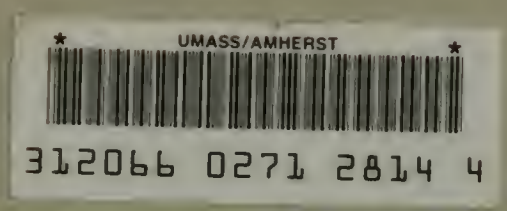
MASS. EA40.2:W29/task 6



Metropolitan District Commission

Water Supply Study and
Environmental Impact Report-2020

Task 6:
Millers and Tully Rivers

Assessment Report

GOVERNMENT DOCUMENTS
COLLECTION
NOV 1 1985
University of Massachusetts
Depository Copy

Submitted To:
Metropolitan District Commission

By:
Wallace, Floyd, Associates Inc.

June, 1985

Metropolitan District Commission

Water Supply Study and
Environmental Impact Report-2020

TASK 6:
MILLERS AND TULLY RIVERS: ASSESSMENT REPORT

Appendix to the Draft Environmental Impact Report

Submitted To:
Metropolitan District Commission

By:
Wallace, Floyd, Associates Inc.

Prepared By:
Wallace, Floyd, Associates Inc.
Arthur D. Little, Inc.
Bechtel Civil & Minerals, Inc.
New England Research, Inc.
Normandeau Associates, Inc.
Cambridge Acoustical Associates, Inc.
Atlantic Environmental Associates, Inc.
Office of Public Archaeology - Boston University
J. E. Edinger Associates, Inc.

June, 1985

FOREWORD

The Metropolitan District Commission (MDC) Water Supply Study and Environmental Impact Report (EIR) is a study of the forty-year water needs of the cities and towns served by the MDC Water Division and a report on the impacts anticipated from alternative means of meeting these needs. The alternatives being studied include: Demand Management, Connecticut River, Millers and Tully Rivers, Merrimack River, User Sources, Watershed Management, Upper Sudbury Watershed, Plymouth Aquifer, and No Action. Desalination was considered in Phase I and will be reported in the Environmental Impact Report.

This long-term water supply study was initiated in 1980 and is projected to be completed in 1986. Phase I of the study was completed in 1980 and involved a review of existing information and recommended methodologies to fill any gaps in the data and to perform the required analyses.

Phase II began in 1982 and involves these major steps:

- projecting water demands of current and potential future users of MDC water supplies to the year 2020;
- assessing the engineering, social, environmental, economic and land use impacts of each of the nine alternatives; and,
- recommending the Preferred Alternative(s) for meeting forecast water needs.

This report assesses the impacts of implementing the Millers and Tully Rivers Alternative. It is one of nine individual assessment reports which are appendices to the Draft Environmental Impact Report. These assessment reports should be read with the companion summary report on assessment findings which compares the impacts of all alternatives and describes the criteria for the selection of a Preferred Alternative(s). The Draft Environmental Impact Report (DEIR) will identify an alternative or combination of alternatives as the Preferred Alternative.

The DEIR (EOEA File #03518) is being prepared in accordance with regulations of the Massachusetts Environmental Policy Act (301 CMR 10) administered by the Executive Office of Environmental Affairs and is subject to public and agency review and comment as required by those regulations.

TABLE OF CONTENTS

Page	
i	FOREWARD
v	LIST OF TABLES
ix	LIST OF FIGURES
1	6.00 SUMMARY
9	6.10 ENGINEERING
95	6.20 WATER QUALITY
135	6.30 ECOLOGY
221	6.40 AIR QUALITY
233	6.41 NOISE
237	6.50 LAND USE
243	6.60 SOCIO-ECONOMIC IMPACTS
249	6.70 SIGNIFICANT CULTURAL RESOURCES
	APPENDICES

LIST OF TABLES

Tables	Page	
Table 6.11-1	18	Results from HYDA Analysis, Millers/Tully Alterantive
Table 6.11-2	21	Potential Transfer, Athol Plus Tully
Table 6.11-3	22	Lost Surplus, Athol Plus Tully
Table 6.11-4	23	No. Days/Mo. Montague Flow Reduced by More Than 5%, Athol Plus Tully
Table 6.11-5	25	Safe Yield Analysis for Millers Alone
Table 6.11-6	27	Increased Supply as Function of Increased Demand
Table 6.11-7	29	Elevation of Quabbin Without Millers
Table 6.11-8	30	Elevation of Quabbin With Millers
Table 6.11-9	31	Reduction of Quabbin in Feet
Table 6.11-10	32	Outflow from Quabbin (MGD) in Excess of the Legal Minimum for the Existing System Without Millers (at 300 MGD Demand)
Table 6.11-11	33	Outflow from Quabbin (MGD) in Excess of the Legal Minimum for the Existing System With Millers (at 335 MGD Demand)
Table 6.11-12	34	Potential Transfers With Millers
Table 6.11-13	35	Actual Transfers With Millers
Table 6.11-14	36	Potential Minus Actual Transfers
Table 6.11-15	37	Safe Yield Analyses for Millers Plus Tully
Table 6.11-16	42	Summary Output for Trial No. 1 Millers Without Tully
Table 6.11-17	43	Summary Output for Trial No. 2 Millers Without Tully
Table 6.11-18	44	Summary of Hydrologic Impacts Millers Without Tully Alternative, Run No. HY-12
Table 6.11-19	46	Quabbin Reservoir End-of-Month Storage, Percent of Net Storage, Millers Without Tully
Table 6.11-20	47	Quabbin Reservoir End-of-Month Elevations, Millers Without Tully
Table 6.11-21	49	Actual Transfers -- Millers to Quabbin, Millers Without Tully

Tables	Page	
Table 6.11-22	50	Streamflow -- Millers River at Athol, Millers Without Tully
Table 6.11-23	51	Streamflow -- Millers River at Erving, MGD, Millers Without Tully
Table 6.11-24	52	Streamflow -- Millers River at Erving, Percent Reduction, Millers Without Tully
Table 6.11-25	53	Streamflow -- Connecticut River at Montague, Millers Without Tully
Table 6.11-26	54	Outflow from Quabbin Reservoir, MGD, Millers Without Tully
Table 6.11-27	55	Streamflow, Chicopee River at Indian Orchard, MGD, Millers Without Tully
Table 6.11-28	56	Streamflow, Connecticut River at Thompsonville, Millers Without Tully
Table 6.11-29	61	Summary Output for Trial No 2 Millers With Tully
Table 6.11-30	62	Summary of Hydrologic Impacts Millers With Tully Alternative, Run No. HY-13
Table 6.11-31	64	Quabbin Reservoir End-of-Month Storage, Percent of Net Storage, Millers With Tully
Table 6.11-32	65	Quabbin Reservoir End-of-Month Elevations, Millers With Tully
Table 6.11-33	66	Streamflow, Millers River at Erving, MGD, Millers With Tully
Table 6.11-34	67	Streamflow, Millers River at Erving, Percent Reduction, Millers With Tully
Table 6.11-35	68	Streamflow, Chicopee River at Indian Orchard, MGD, Millers River With Tully
Table 6.11-36	69	Streamflow, Connecticut River at Thompsonville, CT, Millers With Tully
Table 6.12-1	77	Costs for the Millers River Alternative
Table 6.12-2	78	Costs for the Millers/Tully River Alternative
Table 6.12-3	80	Land Acquisition and Easement Requirements (Millers River Alternative)
Table 6.12-4	81	Land Acquisition and Easement Requirements (Millers/Tully River Alternative)

Tables	Page	
Table 6.14-1	94	Millers River Diversion Only, Impact to Hydropower Generation
Table 6.14-2	94	Millers/Tully River Diversion, Impact to Hydropower Generation
Table 6.21-1	98	Summary of Data Sources and Extent of Available Data Used in Baseline Water Quality Documentation for the Millers/Tully Rivers.
Table 6.21-2	100	Water Quality Parameters Analyzed
Table 6.21-3	103	Millers River Water Quality at Proposed Diversion
Table 6.21-4	105	Tully River Water Quality at Proposed Diversion
Table 6.21-5	109	Major Municipal Wastewater Discharges
Table 6.21-6	110	Population in Years 1980, 1990, and 2000 for Towns in the Millers and Tully River Watersheds
Table 6.21-7	112	Minimum Flow Requirements for Millers and Tully Rivers
Table 6.21-8	115	Millers River Flow, Historic Worst Case Months
Table 6.21-9	116	Percent Occurrence of Flows in Millers River Greater Than or Equal to Minimum Required Flows at Athol, MA
Table 6.21-10	117	Tully River Flow, Historic Worst Case Months
Table 6.21-11	119	Percent Occurrence of Flows Greater Than or Equal to Minimum Required Flows in East Branch of Tully River
Table 6.32-1	138	Indicator Species Selected for the Millers/Tully Rivers Alternative Aquatic Ecology Assessment of Reservoirs
Table 6.32-2	139	Reservoir Aquatic Indicator Species for Millers/Tully Rivers Alternative by Trophic Level and Habitat Type
Table 6.32-3	143	Project Impacts of Millers/Tully Rivers Alternative on Aquatic Ecology of Reservoirs
Table 6.33-1	155	Indicator Species Selected for the Millers River Floodplain Ecology Assessment
Table 6.33-2	159	Summary of Impacts on the Proposed Millers River Diversion on Floodplain Plant and Wildlife Indicator Species.
Table 6.34-1	177	Indicator Species Selected for the Millers-Quabbin Tunnel R.O.W. Assessment

Tables	Page	
Table 6.34-2	181	Summary of Impacts of the Millers-Quabbin R.O.W. on Terrestrial Plant and Wildlife Indicator Species
Table 6.37-1	206	Indicator Species Selected for the Millers River Aquatic Ecology Assessment
Table 6.37-2	209	Summary of Impacts of the Proposed Millers River Diversion on Macroinvertebrate and Fish Indicator Species
Table 6.40-1	222	Annual Summary of Air Quality Data
Table 6.40-2	225	Heavy-Duty Construction Equipment Exhaust Emission Factors
Table 6.40-3	227	Estimates of Fugitive Dust Emissions from Construction
Table 6.40-4	228	Estimated Annual Power Plant Emissions from Electric Energy Demand
Table 6.40-5	230	Massachusetts and National Ambient Air Quality Standards
Table 6.50-1	237	Existing Land Use
Table 6.60-1	246	Summary of Impacts Associated With Millers/Tully River Alternatives

LIST OF FIGURES

Figures	Page	
Figure 6.00-1	2	Millers and Tully Rivers Tunnel Alignment
Figure 6.00-2	4	Millers and Tully Rivers Alternative Intake Locations
Figure 6.00-3	5	Millers and Tully Rivers Alternative Outlet Locations
Figure 6.11-1	57	Quabbin Reservoir End of Month Elevations
Figure 6.11-2	58	Millers River Streamflow at Athol
Figure 6.11-3	60	Connecticut River Streamflow at Thompsonville
Figure 6.12-1	83	Design, Procurement and Construction Schedule
Figure 6.14-1	90	MDC Hydropower Plants
Figure 6.21-1	99	Water Quality Stations on the Millers and Tully Rivers Sampled by Previous Investigators, and Sediment Stations Sampled By NAI in 1982
Figure 6.21-2	107	Millers River Water Quality, Summer 1979 (MDWPC, 1979)
Figure 6.21-3	114	Millers River Low Flow Requirements and Low Flow Durations at Athol
Figure 6.21-4	120	Tully River Low Flow Requirements and Low Flow Duration at Athol
Figure 6.21-5	121	Time of Travel and Flow Profiles in Millers River, Source: U.S. Geological Survey (1969) and Massachusetts Division of Water Pollution Control (1980)
Figure 6.21-6	123	Monthly Millers River Flow at Royalston (USGS, 1981)
Figure 6.21-7	125	Calculated Dissolved Oxygen Profiles in Millers River
Figure 6.22-1	132	Location of Water Quality Assessment Stations on Quabbin Reservoir
Figure 6.33-1	146	Floodplain Community Stations on the Millers and Tully Rivers Sampled by NAI in 1982
Figure 6.34-1	166	Terrestrial Community Stations Along the Millers-Quabbin Tunnel R.O.W. Sampled by NAI in 1982
Figure 6.37-1	204	Benthic Macroinvertebrate and Fish Sampling Stations and Gear Types Used During the 1982 NAI Field Studies on the Millers and Tully Rivers

6.00 SUMMARY

This alternative involves transfer of water from either the Millers River alone or from both the Millers and Tully Rivers to Quabbin Reservoir (see Figure 6.00-1). These two rivers drain southwest from the New Hampshire border. The Tully River joins the Millers River near Athol. The Millers, larger of the two, flows westerly from Athol to its confluence with the Connecticut River.

The design indicates diversion of water through two intakes; one above Athol on the Millers River, and the other along the east branch of the Tully River just below Tully Lake.

In order to avoid ecological and water quality impacts on the rivers, certain minimum flow constraints were incorporated into the design of the alternative. Diversion operations are designed to maintain minimum flows in the river to protect water quality and fisheries. In addition, transfers were also constrained to occur only when flow exceeds 17,000 cfs at Montague on the Connecticut River as required by Massachusetts Legistation Chapter 766, Acts of 1970.

When transfers are allowed from the Millers/Tully Rivers, calculations show that the described operation will result in flow reductions greater than 5% from the intake points to the Millers' confluence with the Connecticut River. The impacts of this flow reduction on the water quality, aquatic ecology, and river floodplains are part of the assessment.

Other operational decisions which affect this alternative are related to Quabbin Reservoir. The decision made in the baseline to hold the Quabbin minimum pool level at 490 feet is incorporated in the design of this alternative. In addition, potential transfers from the Millers/Tully Rivers would not be made when Quabbin is more than 98% full.

Analyses were performed for this alternative using information from the streamflow model to determine potential transfer amounts given hydraulic constraints and incorporated streamflow requirements. Potential transfers are then available to increase the water stored in Quabbin Reservoir when the reservoir is not already full.

The safe yield model incorporates the transfer amount as inflows to Quabbin to determine the increase in system safe yield. Modeling results incorporating the baseline 98.5 percent surrogate reliability showed that the MDC existing

NEW HAMPSHIRE

Tully River

Royalston

Warwick

Northfield

Connecticut River

Tully Lake

Erving

Orange

Millers River

Athol

Phillipston

Montague

Wendell

New Salem

Quabbin Reservoir

Leverett

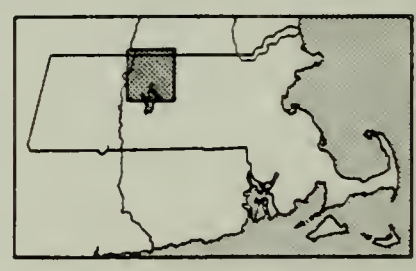
Shutesbury

Legend

- ○ Tunnel Shaft
- ● Spoil Pile
- Proposed Tunnel

Figure 6.00–1.
Millers and Tully Rivers
Tunnel Alignment

0 2.5 5.0 miles



system safe yield would increase by 33 MGD with the Millers option and by 38 MGD with the Millers/Tully option.

Because the transfer of water is by gravity, the transfer capacity and yield of this alternative is partially dependent on the tunnel size. The hydrologic model was run to determine the yield at various tunnel sizes. Marginal cost analyses were performed to determine the most appropriate tunnel sizes for each option. Those sizes appear to be 10 feet for the Millers to Quabbin tunnel under the Millers River option; 11 feet for the Millers to Quabbin tunnel, and 8 feet for the Tully to Millers tunnel under the Millers with Tully River option.

The diversion facilities required for this alternative include: intake, bascule gates, weir, and fish ladder located across the Millers River, and intake and bascule gates in the outlet channel from Tully Dam. Raising the bascule gates causes water to flood over the intake screens. Water collected at the intake screens is piped by gravity flow to the intake shaft and into the proposed Millers to Quabbin tunnel system. The transfer of water to Quabbin through the tunnel is by gravity flow. The right-of-way for the tunnel and the required shafts are illustrated in Figure 6.00-1, 6.00-2, and 6.00-3.

No water treatment is provided for this alternative because the assimilative capacity of Quabbin Reservoir is expected to be sufficient to continue to provide a water supply meeting state and federal drinking water standards.

Capital and operation and maintenance costs were estimated (in 1982 dollars) for the Millers option and Millers/Tully option. The capital cost for the Millers option is $83,300,000, and $112,530,000 for the Millers/Tully option. Annual operating and maintenance costs are estimated at $255,000 and $425,000 (in 1982 dollars), respectively.

The net present value for each alternative has been determined as a basis for comparison between alternatives. The net present value of the Millers option is $142/million gallons, and the net present value of the Millers/Tully option is $170/million gallons.

The effect of implementation of the Millers option or Millers/Tully option on the wholesale water rate of the MDC, if the impacts are spread across all MDC users, is to increase the present wholesale rate by approximately 16 or 22 percent respectively in the early years (1990 to 1994) and increase approximately 4 or 5 percent respectively in the later years (2010 to 2014). The retail rate impact is estimated to increase 3 and 4 percent respectively in the

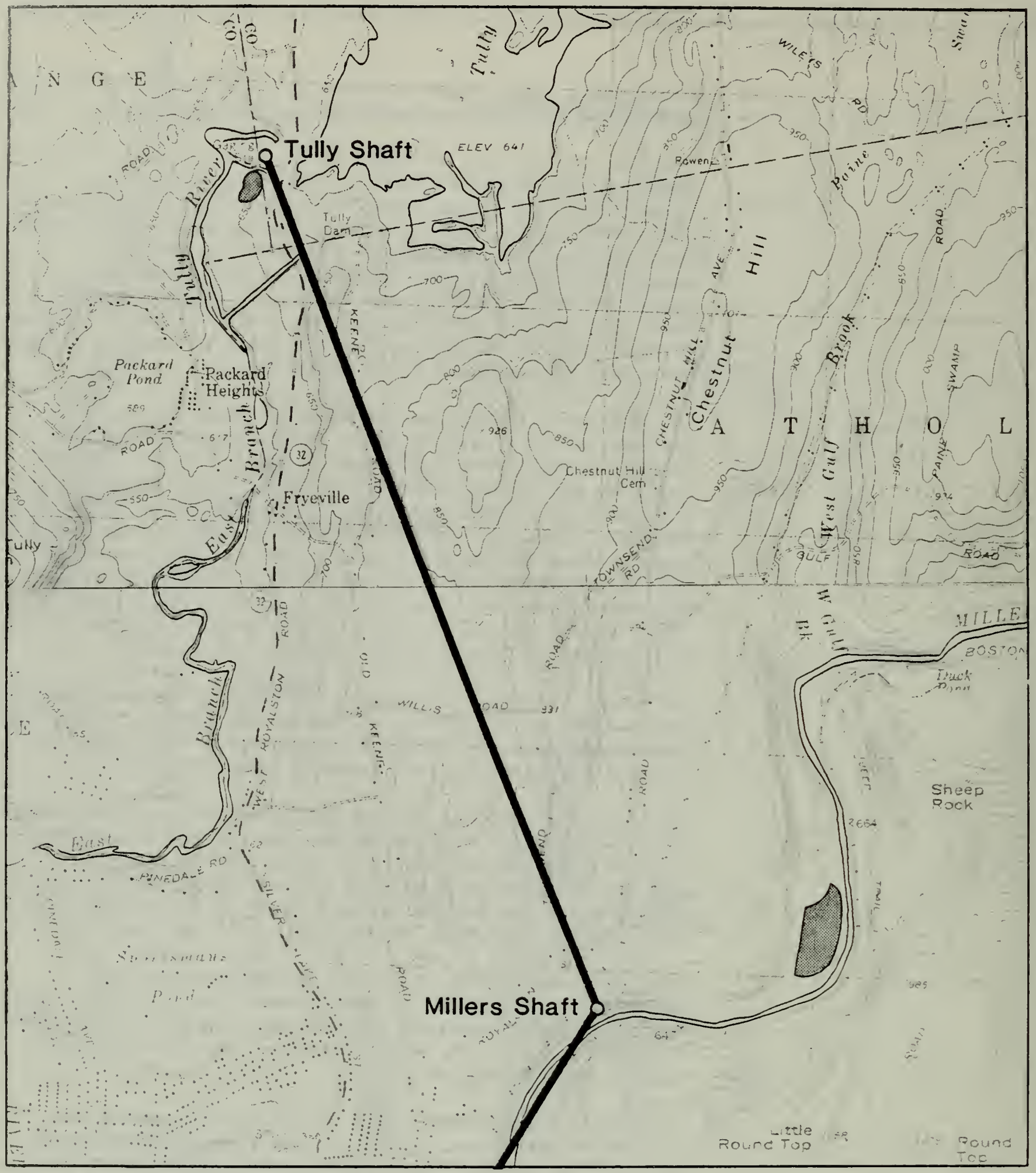
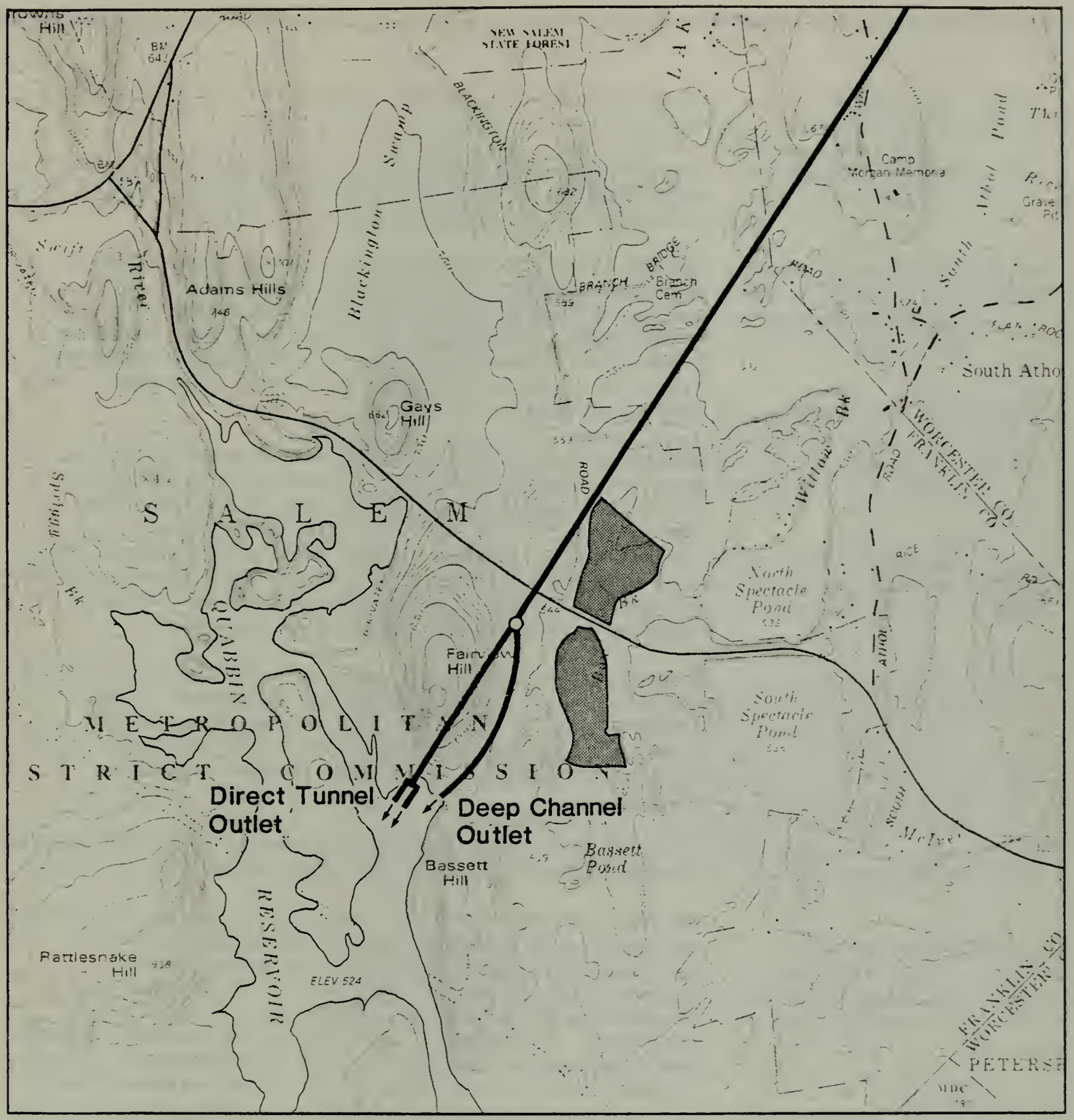


Figure 6.00-2.
Millers and Tully Rivers Intake Locations



Legend

- Proposed Tunnel
- Tunnel Shaft
- Spoil Pile

Figure 6.00-3.
Millers and Tully Rivers Alternative Outlet Locations

0 25000'

early years and to increase one percent in each case later on.

The total cost estimates also assume that the increased MDC capacity will be fully utilized, that is, that water demand will increase by 1990 to 333 MGD and 338 MGD.

The impact of the Millers/Tully Rivers Alternative on hydropower production at the MDC hydropower plants indicated that an overall increase in revenues is expected. At the Windsor Dam Plant and Cosgrove Plant, hydropower production increases. At the Oakdale Plant, hydropower production decreases because at certain high flows, this hydroplant must be by-passed.

Environmental impacts associated with construction of the alternative were assessed. Impacts were considered on terrestrial ecology associated with the Millers/Quabbin tunnel right-of-way and the Tully/Athol tunnel right-of-way. The South Athol Road spoil pile and shaft site will have impacts. The project work in this upland and abandoned field area is expected to have adverse impacts on the drainage to adjacent wetlands.

Increased emission of air pollutants during construction can be expected from construction equipment. Also, increases in fugitive dust can be expected during construction. Construction noise can be expected to be high in the vicinity of shafts, intakes, and other structures.

There will be a significant increase in local and regional direct employment during the construction period.

Without adequate knowledge about the location and condition of significant prehistoric and historical cultural resources at the proposed facility sites for the Millers/Tully Rivers Alternative, it is impossible to predict the effects of the alternative upon cultural resources. In general, considering the size and scale of the construction required for the implementation of the Millers/Tully Rivers Alternative, only a limited impact upon cultural resources is expected. This is true in part because the project area is located within a region that has a low density of archaeological sites.

Environmental impacts associated with operation of the alternative were assessed. Aquatic ecology impacts associated with the transfer of water from the rivers to Quabbin Reservoir include a slightly enhanced rate of eutrophication in Quabbin Reservoir and the likely introduction of undesirable species, such as the lamprey eel, into the reservoir.

Adverse impacts on water quality in the Millers and Tully Rivers because of the Millers River withdrawal and the combined Millers/Tully Rivers withdrawal are not anticipated to be significant, especially considering the low frequency of withdrawals allowed during the biologically critical summer months.

The aquatic ecology of the Millers and Tully Rivers is not expected to change significantly due to water transfer; however, there may be some slight changes due to impingement and entrainment of species at the intake structures.

There is the likelihood of long-term change in floodplain plant communities and wildlife habitat due to the May reduction in the extent of flooding as a result of the proposed transfer. This is considered a localized significant impact.

This alternative presents no potentially significant long-term noise impact. The noise sources associated with water transfer from Millers to Quabbin are quiet and well removed from residential areas.

Although this alternative does not require pumping for water transfer, some power would be required for the operation of gates and the water quality monitoring station. Long-term impacts on air quality might be expected to arise from the combustion products of fossil fuels if these are burned at off-site generating stations to supply electric power demands of the facilities associated with operation of the alternative. The significance of this impacts cannot be evaluated at this time.

Land use impacts possible under the Millers/Tully Rivers Alternative are not considered to be significant. Operation of the alternative is not anticipated to affect competing water users along the Millers River.

6.10 ENGINEERING

The following chapter disusses the hydrologic modeling, conceptual engineering design, and hydropower impacts for the Millers/Tully Rivers Alternative.

6.11 HYDROLOGIC MODELING

The following chapter discusses the results of the safe yield analysis of the existing system with Millers/Tully Rivers Alternative in operation. Initial model runs evaluated Millers River tunnel diameters 12 and 13 feet and a Tully River tunnel of 8 foot diameter. However, integration of the resulting safe yields into an engineering economics evaluation prompted additional model runs using Millers River tunnel sizes of 10 and 11 foot diameters.

In addition, the safe yield model was used to evaluate streamflow and other hydrologic impacts for the Millers Without Tully Alternative and the Millers With Tully Alternative.

MILLERS ALTERNATIVE

The purpose of this analysis is to determine the increase in the safe yield of the MDC water supply system as a result of adding water obtained from the Millers River alone, or from both the Millers River and the East Branch of the Tully River. Water from these rivers would be transferred to Quabbin Reservoir in tunnels.

The first part of the analysis served to determine the potential transfer volumes. This was performed using the HYDA computer program which uses mean daily streamflows for hydrologic input (for the water years 1930 to 1979). Potential daily transfers were calculated as the streamflow in excess of the minimum flow requirements (monthly variables), and also subject to maintaining a minimum flow of 17,000 cfs in the Connecticut River at Montague. Potential transfers were also limited by the hydraulic flow constraints of the tunnels. The daily potential transfer volumes were summed to monthly values for use as input data by the safe yield model.

The safe yield of the existing system (without Sudbury) has been presented in a previous report. A safe yield of 291 MGD was found for the baseline analysis (no monthly failure events). This increased to 294 MGD when a drought management plan was added. After considering sensitivity analyses, a safe yield of 300 MGD was recommended for planning purposes. This yield would result in a surrogate reliability of 98.50 percent (eight monthly failures) for the existing system. The same reliability was adopted for the analysis of safe yield for the system with the Millers alternative.

The safe yield analyses were performed using the same minimum pool levels and operating rules for Quabbin and Wachusett Reservoirs as were used for the analyses of the existing system (without Sudbury). The results for eight Millers options are:

Option	Tunnel Diameter (ft) M	T	Potential Transfers (MGD)	Actual Transfers (MGD)	Incremental Safe Yield (MGD)
1	10	0	54.9	39.0	33.0
2	11	0	59.0	40.7	34.0
3	12	0	61.7	41.9	35.0
4	13	0	63.2	42.3	35.0
5	10	8	62.7	43.2	36.0
6	11	8	69.3	46.0	38.0
7	12	8	73.7	48.1	39.0
8	13	8	76.4	49.5	40.0

Incremental safe yields are the amounts that the system safe yield increased above the 300 MGD associated with the existing system (without Sudbury).

The relatively low increase in both actual transfers and safe yields when compared to the potential transfer volumes is attributable to the performance characteristics of the Millers alternative. During wet years, when potential transfers are high, Quabbin Reservoir is often 100 percent full and transfers are not made. Conversely, during dry years, when space is available in Quabbin, the potential transfer volumes are low. Furthermore, when the alternative is active it causes Quabbin Reservoir to be 100 percent full more often, and even without a transfer from Millers the mean spillway discharge increases as a result of associated high inflows from the natural watershed. Such spillway discharge is lost with respect to use for water supply.

The analyses showed that trial yields could increase considerably without changing the number of monthly failure events. For example, for Option 3, trial yields of 329 to 335 MGD all produced eight monthly failures. The data show that for every increase of 1.00 MGD in the trial yield (demand), there is an increase of 0.88 MGD in the supply. The supply increase occurs because more of the potential transfer can be used when the increasing demands create usable storage volume in Quabbin Reservoir.

The safe yield is highly sensitive to minor changes in the reliability used to define safe yield and to other program variables such as the minimum pool. Examples of this characteristic of the alternative are given in the sections that follow.

INTRODUCTION

The Millers/Tully River Alternative is one of several potential sources of additional water supply the Metropolitan District Commission (MDC) is evaluating. It involves the transfer of water to Quabbin Reservoir from either the Millers River alone or from both the Millers River and the East Branch of the Tully River. The purpose of this document is to report the increase in safe yield that would occur if the alternative were implemented. In performing the analysis, many combinations of diameters for the Athol to Quabbin and the Tully to Athol tunnels were tested. The initial results were evaluated for engineering design, and additional combinations were tested. Some of the results described below pertain to initial tests, and others to the final diameters selected for engineering analysis.

The concepts associated with safe yield and the results obtained from an analysis of the existing MDC water supply

system without Sudbury were presented in Task 4: Safe Yield -- Existing System. Also included were a description of the safe yield model (computer program MDC003) and typical input/output associated with model runs.

In that report, the safe yield of the existing system was found to be 291 MGD for the condition of having no monthly failures and including no reduction in demand during severe droughts. Adding drought management raised the safe yield to 294 MGD. Considering further that the extreme nature of the drought of the middle 1960s impacted a bias on the historic hydrologic record, it was concluded that for planning purposes the "safe yield" of the system should be 300 MGD.

Running the model with a trial yield of 300 MGD and without the drought management algorithm resulted in eight monthly failures out of 600 months simulated. This condition, i.e., eight monthly failures, was adopted as the criteria for establishing the system safe yield with an alternative supply source active in the model. Thus the safe yield of the MDC system, without Sudbury and without drought management but with the Millers Alternative active, is that trail yield that produces eight monthly failures.

PHYSICAL SYSTEM

A detailed description of the physical aspects of the Millers/Tully Alternative is presented in Section 6.12, Facility Design. What follows is a summary. In general, the proposed plan is similar to that proposed in the Northeastern United States Water Supply Study (NEWS) prepared by the Corps of Engineers.

The plan involves two intakes, one along the Millers River in Athol located about 2 miles upstream of the confluence of the Tully River, and the other along the East Branch Tully River located just below the Tully Flood Control Dam. Each intake would have a weir across the river to create a small pond from which water could flow through control gates into a drop structure. After dropping down a shaft, the water would flow through a tunnel to Quabbin Reservoir. The tunnel from Tully (applicable only to the "with Tully" option) would be 8 feet in diameter and about 2.5 miles long. It would extend to the Athol intake structure. The tunnel from the Athol drop shaft to Quabbin Reservoir would be 10 feet in diameter without Tully or 11 feet with Tully. It would be about 8 miles long (depending on the location selected for the outflow structure). The intake control gates and/or river weir would be designed so that they could be adjusted each month to provide for designated minimum downstream discharges. Flow would be by gravity; no pumping is required. No water treatment facility would be required.

POTENTIAL TRANSFERS

The potential transfer is the maximum volume of water that can be transferred each month to Quabbin Reservoir from the Millers/Tully alternative considering streamflow and hydraulic constraints but not the condition of Quabbin Reservoir, i.e., whether there is sufficient space available in Quabbin to accept the transfer without causing a spillway overflow.

Potential transfers were determined by a separate analysis using the HYDA (hydrologic analysis) computer program. The input to HYDA is from a magnetic tape furnished by the USGS containing historic mean daily streamflows for gaging stations for their entire period of record. The records from four stations were used:

	Station Name	Drainage Area (sq. miles)	Period Available (years)
1.	Millers R./S. Royalston, MA	187.0	1940-1979
2.	E. Br. Tully R./Athol, MA	50.4	1915-1979
3.	Millers R./Erving, MA	375.0	1915-1979
4.	Conn. R./Montague, MA	7,865.0	1904-1979

The proposed intake along the Millers River at Athol has a drainage area of 200 square miles and is located a short distance downstream from the South Royalston gaging station. The period of historic record that has been selected for analysis is 50 years (1930-1979). In order to estimate the flow of the Millers River at the proposed intake, the ratio of drainage areas method was used and was based on the Erving gage from 1930 to 1939 and the South Royalston gage from 1940 to 1979. The proposed Tully intake has a drainage area of 50 square miles, and the historic flows from the East Branch Tully River gage were used without transformation.

The HYDA program calculates the potential transfer for each day of the historic record. The daily transfers are summed to obtain a monthly value which becomes the input to the safe yield model.

For each day, the HYDA program compares the historic flow at Athol and at Tully with a required minimum discharge that has been established for each location for fish habitat requirements (see Section 6.21, Water Quality of Millers/Tully Rivers). The minimum flow values are:

Month	Minimum Flow (cfs) Millers River (Athol)	E. Br. Tully River
Jan	100	25
Feb	100	25
Mar	250	63
Apr	800	200
May	250	63
Jun	250	63
Jul	400	100
Aug	200	50
Sep	150	38
Oct	400	100
Nov	400	100
Dec	100	25

Transfers were also constrained to the excess flow above 17,000 cfs at Montague on the Connecticut River, using the historic daily flow minus the previous day's transfer at Tully, Athol, or both. This was to allow for a one-day travel time from the diversion points to Montague. Transfers are allowed 365 days per year in the analysis.

The program also calculates the maximum transfer that is possible considering hydraulic constraints. The diameters of both the Tully-to-Athol and the Athol-to-Quabbin tunnels are provided as input data.

A series of HYDA runs were made for various combinations of tunnel diameters. The results are summarized in Table 6.11-1. In this table, the "Potential Transfer-MGD" represents the input to the safe yield model. The "Lost Surplus-MGD" data represent the flows that could have been transferred without violating the minimum discharge constraints, but were precluded from transfer by hydraulic constraints (i.e., the tunnel diameters were too small). The lost surplus summary values can be misleading because they are largely attributable to the major floods of March 1936 and September 1938, which occurred prior to the construction of upstream flood control reservoirs.

A matter of interest for ecological studies is the location where the operation of the Millers/Tully alternative would cause downstream reductions of flows of 5 percent (or less). It had been determined that the entire Millers River would be subject to reductions in excess of 5 percent, but it was uncertain whether the effect would extend to the Connecticut River. Based on a ratio of drainage areas, Millers plus Tully (250 square miles) is only 3.2 percent of Montague (7,865 square miles); and, therefore, the flow reduction at Montague would be expected to be 3.2 percent if all of the Millers and Tully

TABLE 6.11-1

RESULTS FROM HYDA ANALYSIS, MILLERS/TULLY ALTERNATIVE

Run	DM	DT	Athol	Tully	Athol Plus Tully
			Potential Transfer - MGD		
1	10	0	54.85	--	--
2	11	0	59.02	--	--
3	12	0	61.65	--	--
4	13	0	63.21	--	--
5	10	8	54.85	16.09	62.65
6	11	8	59.02	16.16	69.26
7	12	8	61.65	16.19	73.67
8	13	8	63.21	16.21	76.43
9	14	8	64.05	16.22	78.16
10	15	8	64.39	16.23	79.08
11	15	10	64.39	16.37	79.08
			Lost Surplus - MGD		
1	10	0	11.30	--	--
2	11	0	7.05	--	--
3	12	0	4.38	--	--
4	13	0	2.79	--	--
5	10	8	11.29	0.52	19.31
6	11	8	7.05	0.46	12.55
7	12	8	4.38	0.42	8.06
8	13	8	2.79	0.41	5.26
9	14	8	1.95	0.39	3.50
10	15	8	1.59	0.39	2.56
11	15	10	1.59	0.24	2.56
			No. Days Montague Flow Reduced More Than 5% (Total for 50 years)		
1	10	0	0	--	--
2	11	0	15	--	--
3	12	0	36	--	--
4	13	0	50	--	--
5	10	8	0	0	0
6	11	8	15	0	59
7	12	8	36	0	125
8	13	8	50	0	155
9	14	8	56	0	166
10	15	8	58	0	177
11	15	10	58	0	177

TABLE 6.11-1 (Continued)

RESULTS FROM HYDA ANALYSIS, MILLERS/TULLY ALTERNATIVE

Run	DM	DT	Athol	Tully	Athol Plus Tully
			Maximum Percentage Reduction in Montague Flow		
1	10	0	4.64	--	--
2	11	0	5.90	--	--
3	12	0	7.22	--	--
4	13	0	8.34	--	--
5	10	8	4.64	2.43	4.69
6	11	8	5.90	2.43	5.96
7	12	8	7.22	2.43	7.30
8	13	8	8.34	2.43	8.72
9	14	8	10.27	2.43	10.39
10	15	8	11.47	2.43	12.07
11	15	10	11.47	2.43	12.07

streamflows were transferred. Because the daily transfer volumes and the Montague daily flows were available in the HYDA analysis, a routine was included that determined the percentage reduction each day and counted the number of days in which a 5 percent reduction was exceeded. The program also determined the maximum percentage reduction during 50 years (18,250 days--February 29 is excluded in the models with respect to both supply and demand). The results are shown in Table 6.11-1. A special analysis was made for Run No. 8 (DM=13, DT=8) to obtain a distribution:

Percentage Reduction	No. of Days
5.00-5.99	114
6.00-6.99	25
7.00-7.99	12
8.00-8.72	4
	155 total

The reason that a few days exceeded 5 percent is not clear, but it may be due to some unusual rainfall events and/or regulation of the dams upstream of the gaging stations. (These also influence the time lag relationship between the intake and Montague.)

The monthly values for Option No. 6, Athol plus Tully, are shown in Tables 6.11-2, 6.11-3, and 6.11-4. Table 6.11-2 shows the potential transfers, Table 6.11-3 the lost surplus, and Table 6.11-4 the number of days each month that the Montague flow was reduced by more than 5 percent.

SAFE YIELD MODEL OPERATION

The Millers/Tully alternative is activated in the safe yield model by changing the value of input variable IALT(2) from zero to two (or to one if the alternative is to only operate during months in which the combined storage of Quabbin and Wachusett is below a designated value, e.g., 98 percent of total storage).

Values for program variable QMSFMT(M), Quabbin Maximum Storage for Millers Transfer (monthly values), must also be input. These values, expressed as fractions, are used to determine the storage in Quabbin above which no transfers would be made.

During each monthly simulation, the program starts with the storage in Quabbin at the beginning of the month, adds natural inflows, Shaft 8 inflows, and precipitation. It then subtracts evaporation losses, minimum discharge requirements, Chicopee withdrawals, and transfers to Wachusett. The resulting storage is a temporary value

TABLE 6.11-2

02/17/84 MILLERS/TULLY POTENTIAL TRANSFER, DM=11, DT=8

56 ATHOL PLUS TULLY POTENTIAL TRANSFER IN MG BASED ON DM = 11.0 FT DT = 8.0 FT
MONTAGUE MINIMUM DISCHARGE OF 17000. CFS; AND

	QMINTU =	100.	100.	25.	25.	25.	63.	200.	63.	63.	100.	50.	38.	CFS
	QMINAT =	400.	400.	100.	100.	100.	250.	800.	250.	250.	400.	200.	150.	CFS
IY	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOT
1	1930	0.	0.	0.	573.	2313.	3399.	0.	163.	16.	0.	0.	0.	6463.
2	1931	0.	0.	0.	0.	0.	2789.	6570.	4246.	3153.	0.	0.	0.	16758.
3	1932	0.	0.	944.	5079.	0.	0.	6499.	1171.	0.	0.	0.	0.	13692.
4	1933	0.	2134.	0.	0.	0.	0.	13965.	1283.	0.	0.	30.	697.	18110.
5	1934	0.	0.	0.	0.	0.	4340.	9644.	4735.	467.	0.	0.	393.	19578.
6	1935	0.	296.	4315.	5316.	0.	8869.	391.	1902.	938.	386.	0.	0.	22412.
7	1936	0.	256.	656.	0.	0.	13850.	4632.	471.	0.	0.	0.	0.	19866.
8	1937	0.	6.	7187.	12989.	3771.	0.	1599.	8553.	2301.	80.	0.	0.	36486.
9	1938	169.	3391.	3573.	4609.	5019.	3038.	24.	1510.	0.	2156.	1667.	7460.	32614.
10	1939	411.	235.	8421.	0.	0.	2969.	7412.	1858.	0.	0.	0.	0.	21305.
11	1940	0.	23.	0.	0.	0.	323.	18035.	8196.	3385.	0.	0.	0.	29962.
12	1941	0.	753.	1609.	1527.	680.	0.	13.	0.	0.	0.	0.	0.	4581.
13	1942	0.	0.	372.	178.	0.	13455.	0.	128.	1758.	0.	0.	0.	15891.
14	1943	0.	794.	2468.	0.	1418.	9538.	573.	15856.	435.	0.	36.	0.	31119.
15	1944	103.	1347.	0.	0.	0.	4267.	4086.	1795.	4071.	0.	0.	0.	15668.
16	1945	0.	0.	0.	1612.	0.	14578.	2331.	14063.	4519.	1274.	0.	0.	38377.
17	1946	0.	493.	2450.	3076.	0.	13214.	0.	6854.	4550.	0.	0.	0.	30638.
18	1947	428.	0.	15.	0.	3443.	8407.	3022.	5317.	1157.	0.	0.	0.	21789.
19	1948	0.	217.	0.	0.	0.	9620.	4986.	10180.	3227.	0.	0.	0.	28230.
20	1949	0.	355.	161.	6177.	1437.	4196.	212.	1421.	0.	0.	0.	0.	13960.
21	1950	0.	0.	741.	1700.	0.	2258.	2584.	1208.	638.	0.	0.	38.	9167.
22	1951	0.	3206.	7949.	452.	3614.	7607.	5600.	572.	0.	0.	0.	0.	29001.
23	1952	89.	7836.	2917.	5374.	3554.	4497.	5426.	3704.	3376.	0.	0.	0.	36772.
24	1953	0.	0.	1571.	4436.	5052.	9979.	13022.	11387.	0.	0.	0.	0.	45446.
25	1954	0.	0.	5629.	0.	3597.	5639.	2333.	11372.	915.	11.	0.	6909.	36406.
26	1955	0.	4510.	7765.	864.	0.	5337.	1692.	3548.	344.	0.	1062.	0.	25123.
27	1956	3061.	9687.	0.	4062.	0.	0.	11923.	11238.	1153.	0.	0.	0.	41124.
28	1957	0.	93.	65.	1324.	645.	4210.	251.	788.	0.	0.	0.	0.	7375.
29	1958	0.	0.	7647.	3529.	0.	1057.	11202.	8965.	0.	0.	0.	0.	32400.
30	1959	0.	35.	0.	2065.	0.	2850.	6791.	1190.	0.	0.	0.	0.	12932.
31	1960	3236.	4428.	12208.	3924.	1507.	631.	16736.	5740.	684.	0.	0.	2366.	51461.
32	1961	644.	801.	318.	0.	2032.	7539.	7291.	5112.	0.	0.	0.	0.	23738.
33	1962	0.	0.	0.	0.	0.	1587.	8695.	2611.	0.	0.	0.	0.	12893.
34	1963	1660.	220.	2180.	0.	0.	3318.	6551.	888.	0.	0.	0.	0.	14817.
35	1964	0.	391.	0.	3521.	0.	9715.	2060.	583.	0.	0.	0.	0.	16271.
36	1965	0.	0.	492.	0.	0.	0.	26.	86.	0.	0.	0.	0.	604.
37	1966	0.	0.	0.	0.	0.	6076.	6.	1023.	0.	0.	0.	0.	7105.
38	1967	0.	28.	0.	0.	0.	171.	8073.	14650.	1627.	0.	0.	0.	24548.
39	1968	0.	0.	2878.	0.	0.	8609.	2707.	1800.	6232.	1303.	0.	0.	23530.
40	1969	0.	223.	4920.	0.	0.	4118.	10561.	4096.	670.	244.	2879.	0.	27711.
41	1970	0.	4781.	4305.	528.	8739.	2256.	8604.	5124.	0.	0.	0.	0.	34337.
42	1971	0.	0.	0.	0.	0.	420.	6762.	7405.	0.	0.	0.	0.	14586.
43	1972	0.	0.	194.	0.	0.	8613.	9318.	12766.	5462.	25.	0.	0.	36377.
44	1973	0.	1758.	6875.	9013.	5531.	14067.	4088.	8858.	1596.	3961.	160.	0.	55908.
45	1974	0.	0.	8663.	7214.	4336.	6617.	260.	5514.	537.	0.	0.	0.	33141.
46	1975	0.	195.	2035.	0.	2586.	7299.	2877.	911.	1676.	152.	481.	3896.	22108.
47	1976	8926.	7138.	3518.	2788.	12515.	13353.	2643.	5788.	0.	59.	2195.	0.	58924.
48	1977	126.	0.	641.	0.	0.	12677.	7693.	2561.	0.	0.	0.	0.	23698.
49	1978	3934.	1524.	7686.	10415.	2548.	3796.	4344.	1646.	594.	0.	0.	0.	36486.
50	1979	0.	0.	0.	4283.	0.	16448.	2620.	7983.	1250.	0.	0.	0.	32583.
	TOT	22787.	57155.	123366.	106627.	74336.	287595.	256732.	238815.	56731.	9652.	8509.	21760.	1264063.

69.3 M41b

TABLE 6.11-3
02/17/84 MILLERS/TULLY POTENTIAL TRANSFER, DM=11, DT=8

59 LOST SURPLUS AMOUNTS (MG) - ATHOL PLUS TULLY DM = 11.0 FT DT = 8.0

IY	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOT
1	1930	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	1931	0.	0.	0.	0.	0.	453.	0.	0.	0.	0.	0.	0.	453.
3	1932	0.	0.	0.	0.	0.	0.	1816.	0.	0.	0.	0.	0.	1816.
4	1933	0.	0.	0.	0.	0.	0.	6377.	0.	0.	0.	0.	14.	6391.
5	1934	0.	0.	0.	0.	0.	1448.	1931.	0.	0.	0.	0.	0.	3379.
6	1935	0.	0.	690.	2646.	0.	0.	0.	0.	0.	0.	0.	0.	3336.
7	1936	0.	0.	0.	0.	0.	33307.	304.	0.	0.	0.	0.	0.	33611.
8	1937	0.	0.	779.	250.	0.	0.	0.	82.	0.	0.	0.	0.	1111.
9	1938	0.	1142.	761.	3758.	0.	0.	0.	0.	0.	97.	535.	27199.	33492.
10	1939	0.	0.	3579.	0.	0.	5.	113.	0.	0.	0.	0.	0.	3697.
11	1940	0.	0.	0.	0.	0.	0.	11162.	1655.	673.	0.	0.	0.	13490.
12	1941	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	1942	0.	0.	0.	0.	0.	6442.	0.	0.	0.	0.	0.	0.	6442.
14	1943	0.	0.	2.	0.	0.	17.	0.	355.	0.	0.	0.	0.	374.
15	1944	0.	0.	0.	0.	0.	474.	0.	0.	5244.	0.	0.	0.	5718.
16	1945	0.	0.	0.	0.	0.	3998.	0.	2002.	0.	0.	0.	0.	6001.
17	1946	0.	0.	0.	0.	0.	3333.	0.	141.	0.	0.	0.	0.	3474.
18	1947	0.	0.	0.	0.	0.	348.	0.	0.	0.	0.	0.	0.	348.
19	1948	0.	0.	0.	0.	0.	6591.	462.	586.	0.	0.	0.	0.	7639.
20	1949	0.	0.	0.	1713.	0.	0.	0.	0.	0.	0.	0.	0.	1713.
21	1950	0.	0.	0.	0.	0.	207.	0.	0.	0.	0.	0.	0.	207.
22	1951	0.	816.	677.	0.	648.	0.	0.	0.	0.	0.	0.	0.	2141.
23	1952	0.	0.	0.	953.	0.	0.	0.	0.	0.	0.	0.	0.	953.
24	1953	0.	0.	0.	642.	13.	3197.	371.	0.	0.	0.	0.	0.	4224.
25	1954	0.	0.	177.	0.	0.	0.	0.	0.	0.	0.	0.	442.	619.
26	1955	0.	0.	47.	0.	0.	0.	0.	7.	0.	0.	0.	0.	54.
27	1956	1599.	471.	0.	1264.	0.	0.	600.	4547.	0.	0.	0.	0.	8481.
28	1957	0.	0.	0.	10.	0.	0.	0.	0.	0.	0.	0.	0.	10.
29	1958	0.	0.	349.	0.	0.	0.	0.	317.	0.	0.	0.	0.	666.
30	1959	0.	0.	0.	356.	0.	0.	1171.	0.	0.	0.	0.	0.	1527.
31	1960	798.	0.	1660.	119.	0.	0.	4922.	0.	0.	0.	0.	367.	7867.
32	1961	0.	0.	0.	0.	36.	70.	0.	0.	0.	0.	0.	0.	106.
33	1962	0.	0.	0.	0.	0.	126.	2159.	0.	0.	0.	0.	0.	2285.
34	1963	0.	0.	0.	0.	0.	1084.	0.	0.	0.	0.	0.	0.	1084.
35	1964	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
36	1965	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
37	1966	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
38	1967	0.	0.	0.	0.	0.	0.	0.	891.	77.	0.	0.	0.	968.
39	1968	0.	0.	0.	0.	0.	5691.	304.	0.	48.	0.	0.	0.	6043.
40	1969	0.	0.	46.	0.	0.	0.	2722.	1059.	0.	0.	311.	0.	4139.
41	1970	0.	0.	0.	0.	1632.	110.	0.	591.	0.	0.	0.	0.	2334.
42	1971	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
43	1972	0.	0.	0.	0.	0.	1274.	2061.	207.	346.	0.	0.	0.	3887.
44	1973	0.	0.	356.	806.	1504.	2478.	0.	0.	0.	0.	0.	0.	5145.
45	1974	0.	0.	6787.	1451.	0.	0.	0.	0.	0.	0.	0.	0.	8238.
46	1975	0.	0.	0.	0.	91.	690.	282.	0.	0.	0.	0.	1769.	2833.
47	1976	1023.	98.	0.	2216.	5143.	0.	299.	0.	0.	0.	0.	0.	8778.
48	1977	0.	0.	0.	0.	0.	7799.	534.	0.	0.	0.	0.	0.	8333.
49	1978	0.	0.	103.	1302.	202.	19.	0.	0.	0.	0.	0.	0.	1625.
50	1979	0.	0.	0.	387.	0.	13480.	0.	194.	0.	0.	0.	0.	14060.
	TOT	3420.	2528.	16012.	17875.	9270.	92642.	37590.	12635.	6388.	97.	846.	29792.	229092.

12.6 MGD

TABLE 6.11-4

02/17/84 MILLERS/TULLY POTENTIAL TRANSFER, DM=11, DT=8

68 NO DAYS/MO MONTAGUE FLOW REDUCED BY MORE THAN 5% - ATHOL PLUS TULLY DM = 11.0 FT DT = 8.0 FT
MAX EXCESS = 5.96 PERCENT

IY	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOT
1	1930	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	1931	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3	1932	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4	1933	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.
5	1934	0.	0.	0.	0.	0.	2.	0.	0.	0.	0.	0.	0.	2.
6	1935	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	1936	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	1937	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	1.
9	1938	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	2.	1.	4.
10	1939	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	1.
11	1940	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
12	1941	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	1942	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
14	1943	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.
15	1944	0.	0.	0.	0.	0.	0.	0.	0.	2.	0.	0.	0.	2.
16	1945	0.	0.	0.	0.	0.	2.	0.	0.	0.	0.	0.	0.	2.
17	1946	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	1947	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	1.
19	1948	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20	1949	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
21	1950	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
22	1951	0.	0.	0.	0.	3.	2.	0.	0.	0.	0.	0.	0.	5.
23	1952	0.	0.	0.	2.	3.	0.	0.	0.	0.	0.	0.	0.	5.
24	1953	0.	0.	0.	1.	2.	0.	0.	0.	0.	0.	0.	0.	3.
25	1954	0.	0.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	2.
26	1955	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
27	1956	1.	2.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	4.
28	1957	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
29	1958	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	1.
30	1959	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	1.
31	1960	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
32	1961	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
33	1962	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
34	1963	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
35	1964	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
36	1965	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
37	1966	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
38	1967	0.	0.	0.	0.	0.	0.	0.	0.	1.	0.	0.	0.	1.
39	1968	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
40	1969	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.
41	1970	0.	0.	0.	0.	4.	1.	0.	0.	0.	0.	0.	0.	5.
42	1971	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
43	1972	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
44	1973	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.
45	1974	0.	0.	0.	1.	0.	1.	0.	0.	0.	0.	0.	0.	2.
46	1975	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	1.
47	1976	1.	0.	0.	0.	3.	0.	0.	0.	0.	0.	0.	0.	4.
48	1977	0.	0.	0.	0.	0.	2.	0.	0.	0.	0.	0.	0.	2.
49	1978	0.	0.	0.	4.	2.	0.	0.	0.	0.	0.	0.	0.	6.
50	1979	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	TOT	2.	2.	6.	12.	19.	11.	0.	0.	3.	0.	2.	2.	59.

having a range that could be in excess of full capacity to less than zero.

At this point, transfers from Millers/Tully are calculated. Variable TAVAIL (transfer available) is set equal to the potential transfer for the month and year involved--this value is read directly from the input record that was prepared by the HYDA program (e.g., similar to Table 6.11-2). Variable TDESIR (transfer desired) is then found by subtracting the temporary storage from the maximum value of storage for which transfers are to be made. The latter is the full storage of Quabbin multiplied by QMSFMT(M). The QMSFMT values were all input as 1.00; therefore, either all of the potential transfer volume is used or Quabbin achieves a temporary storage equal to full storage. If the value of TDESIR is negative, it is reset to zero. No transfer is made if Quabbin's storage equals or exceeds the designated maximum transfer storage value.

The actual transfer is found as the minimum of TAVAIL and TDESIR. This value is added to the temporary storage of Quabbin. The program then performs the usual final check to determine whether the new temporary storage value exceeds the maximum storage capacity (in which case the excess is spilled), or whether it is less than the minimum pool storage (in which case the original withdrawals are decreased, the minimum discharge is decreased, and/or the reservoir is allowed to drop below its minimum pool--any of which result in a failure event).

The transfers from Millers/Tully are identified as Point No. 6 in the program. The potential transfers, PT(6), and actual transfers, AT(6), can be printed as tables. The sum of these values for 50 years, SPT(6) and SAT(6), appear at the top of the summary page for each trial.

BASIC SAFE YIELD RESULTS

A series of runs were made to determine the safe yield of the MDC system with the Millers alternative alone and with Millers plus Tully. Tunnel diameters of 12 feet for Millers and 8 feet for Tully were selected for initial baseline analysis. A reliability of 98.50 percent (8 monthly failures) was used to define safe yield, this being the same reliability that is associated with a yield of 300 MGD for the existing system (without Sudbury).

ANALYSIS OF MILLERS ALONE

The results from this set of analyses are shown in Table 6.11-5. Runs having trial yields ranging from 329 to 335 MGD all produced the same reliability of 98.50 percent (eight monthly failures). The program selects the greatest trial yield in the set of values as the safe yield. The

TABLE 6.11-5

SAFE YIELD ANALYSIS FOR MILLERS ALONE
(DM=12, DT=0)

Run	Trial Yield (MGD)	Actual Yield (MGD)	Reliability Percentage	Number of Monthly Failures	Actual Transfer AT(6) (MGD)	AT(6) Percentage of PT(6)*	Quabbin Discharge QO(11) MGD**
V-10***	300	298.4	98.5	8	-	-	65.1
V-19	300	300.0	99.83	0	31.7	51.4	84.1
V-19	310	310.0	99.67	1	34.8	56.4	77.5
V-20	315	314.5	99.17	4	36.6	59.3	75.2
V-19	320	319.0	98.84	6	37.6	61.0	71.6
V-20	321	319.9	98.84	6	37.7	61.2	70.9
V-20	322	320.8	98.84	6	38.0	61.6	70.1
V-20	323	321.6	98.84	6	38.5	62.4	69.5
V-20	324	322.5	98.67	7	38.9	63.0	68.9
V-20	325	323.4	98.67	7	39.2	63.6	68.4
V-20	327	325.2	98.67	7	39.6	64.2	67.0
V-14	328	326.0	98.67	7	39.8	64.6	66.5
V-14	329	326.9	98.50	8	40.2	65.2	65.7
V-10	330	327.8	98.50	8	40.4	65.6	65.1
V-13	331	328.7	98.50	8	40.6	65.8	64.3
V-13	332	329.6	98.50	8	40.8	66.1	63.6
V-13	333	330.4	98.50	8	41.1	66.7	63.2
V-13	334	331.4	98.50	8	41.5	67.3	62.7
V-14	335	332.3	98.50	8	41.9	67.9	62.1
V-14	336	333.2	98.34	9	42.3	68.6	61.2
V-14	337	334.1	98.34	9	42.8	69.4	60.9
V-16	340	336.7	98.34	9	43.6	70.7	59.4
V-16	345	341.2	97.84	12	45.1	73.1	56.4
V-16	350	345.6	97.67	13	47.5	77.0	53.8
V-18	355	350.0	97.50	14	48.8	79.1	50.8
V-18	360	354.2	97.17	16	50.3	81.5	48.5

*Potential transfer, PT(6) = 61.65 MGD
**Mean legal minimum discharge is 29.7 MGD
***Without Millers alternative (reference safe yield)

two-decimal precision used in reporting safe yields is unwarranted, but it is used for purposes of identification and for sensitivity analyses.

For a trial yield of 335 MGD, the actual transfer [AT(6)] from the Millers alone is 41.87 MGD, which is 67.9 percent of the potential transfer [PT(6)] of 61.65 MGD. The reason for this relatively low rate of utilization of the potential transfer lies in the way in which the alternative operates.

The 50-year hydrologic input contains alternating wet and dry cycles of roughly 12 years' duration. The potential transfers from Millers are high during the wet cycles and low during the dry cycles, and these coincide with high and low reservoir storages in Quabbin. During the wet cycles, Quabbin is often 100 percent full and, therefore, no transfer is made from the Millers source. Conversely, when Quabbin's storage is low, there is relatively little transfer available.

During wet cycles, the Millers transfer causes Quabbin to be filled to capacity more often than it would be filled without Millers. As a result, the natural inflow to Quabbin (including the Ware River transfers from Shaft 8) is more often wasted as spillway overflow. As the trial yield is increased, thereby causing more water to be withdrawn, the storage levels in Quabbin are reduced. This allows more of the potential supply from Millers to be transferred. It also causes Quabbin to be 100 percent full for fewer months, thereby reducing the spillage, which is wasted with respect to water demand.

The effect is shown in Table 6.11-6. For each trial yield from 329 to 335 MGD, the actual transfer from Millers, AT(6), and the total outflow from Quabbin, QO(11), are shown. The increase in Millers transfer, Δ AT(6), and the decrease in Quabbin outflow, Δ QO(11), are also shown, as is their sum, $\Sigma\Delta$. For every increase of 1.00 MGD in trial yield (demand), there is an associated increase in supply of about 0.88 MGD (mean value of $\Sigma\Delta$).

The safe yield for the existing system (without Sudbury), using a reliability of 99.80 percent (no monthly failures), is 291.1 MGD. A similar analysis (no monthly failures) with Millers produces a safe yield of 309 MGD, for an increase of 18 MGD. However, when the two scenarios are analyzed using a reliability of 98.50 percent, the safe yields are 300 and 335 MGD, for an increase of 35 MGD. Even for a trial yield of 360 MGD, which represents an attempt to use all of the potential transfer of 61.65 MGD, there are only 16 monthly failures, all of which occur during the record drought of the mid-1960s.

TABLE 6.11-6

INCREASED SUPPLY AS FUNCTION OF INCREASED DEMAND

TYIELD MGD	AT(6) (MGD)	Δ AT(6) (MGD)	QO(11) (MGD)	Δ QO(11) (MGD)	ΣΔ (MGD)
329	40.17		65.68		
		0.26		0.55	0.81
330	40.43		65.13		
		0.12		0.85	0.97
331	40.55		64.28		
		0.22		0.67	0.89
332	40.77		63.61		
		0.36		0.45	0.81
333	41.13		63.16		
		0.39		0.49	0.88
334	41.52		62.67		
		0.35		0.56	0.91
335	41.87		62.11		
Mean Value of ΣΔ :					0.88

The incremental safe yield of 35 MGD attributable to the Millers alternative (without Tully, and using a 12-foot diameter tunnel) must, therefore, be considered as highly sensitive to changes in the reliability that is associated with the definition of safe yield.

ADDITIONAL ANALYSIS--MILLERS ALONE

Run V-25 was made to determine the differences in elevation of Quabbin Reservoir due to the Millers-alone alternative. Trial yields of 300 and 335 MGD were used. The Millers alternative was inactive for the first trial and active for the second. Each trial has a safe yield reliability of 98.50 percent (eight monthly failures). Table 6.11-7 shows the elevations of Quabbin without Millers, Table 6.11-8 shows the elevation with Millers, and Table 6.11-9 shows the reduction in feet (positive values indicate that the elevation was lower with Millers). The mean difference for 50 years was -1.5 feet, although individual months ranged from plus 4.7 feet to minus 13.2 feet.

Other tables of interest were also produced from Run V-25. Table 6.11-10 shows the outflow from Quabbin (MGD) in excess of the legal minimum for the existing system without Millers (at 300 MGD demand). Table 6.11-11 shows the same computation with Millers (at 335 MGD). The mean values increase from 24.96 to 32.44 MGD, showing an increase of 7.48 MGD in spillage.

Three tables apply to the with-Millers case only. Table 6.11-12 shows the potential transfers, Table 6.11-13 the actual transfers, and Table 6.11-14 shows the difference, all in MGD.

ANALYSIS OF MILLERS PLUS TULLY

The basic analysis was performed for a 12-foot tunnel from Athol to Quabbin and an 8-foot tunnel from Tully to Athol. The results are shown in Table 6.11-15.

Comparison of the Millers-alone with the Millers Plus Tully output at their respective safe yields shows the following:

	Millers Alone	Millers Plus Tully
Safe Yield (MGD)	335.01	339.01
Potential Transfer (MGD)	61.65	73.67
Actual Transfer (MGD)	41.87	48.14
PT/AT (percentage)	67.9	65.4
Quabbin Outflow (MGD)	62.11	64.00

TABLE 6.11-7 ELEVATION OF QUABBIN WITHOUT MILLERS

RUN V-25 7/06/83 MILLER/TULLY ALTER., DM=12, DT=0 NTS = 1 NTTS = 2 TYIELD = 300. MGD

23 2 1 2 1 1 1 2 QUABBIN RESERVOIR END-OF-MONTH ELEV (BOSTON CITY BASE)

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
													528.0	
1	1930	526.7	525.8	525.0	524.3	523.7	523.9	523.8	523.1	522.1	521.4	519.7	518.2	523.2
2	1931	516.9	516.0	515.0	513.9	513.0	513.9	517.0	518.1	518.7	517.4	516.7	515.5	516.0
3	1932	514.4	513.2	512.8	514.1	514.2	514.7	517.1	516.6	515.2	513.6	512.0	510.9	514.1
4	1933	511.6	513.5	513.1	513.3	514.1	516.0	521.1	521.6	520.5	518.8	517.6	518.7	516.6
5	1934	518.8	518.4	518.1	518.5	518.1	520.5	523.9	525.1	525.0	523.6	522.0	522.2	521.2
6	1935	521.9	522.1	522.8	524.2	524.3	526.5	528.3	528.1	528.0	527.2	525.5	524.6	525.3
7	1936	523.1	522.6	521.8	522.5	522.2	528.8	530.0	529.9	529.3	528.0	526.8	525.6	525.9
8	1937	525.3	524.6	526.9	529.3	530.0	529.9	530.0	530.0	529.1	528.0	527.3	526.5	528.1
9	1938	525.8	527.2	528.4	528.7	529.6	530.0	530.0	529.7	529.9	530.0	529.8	530.0	529.1
10	1939	530.0	530.0	530.0	530.0	530.0	530.0	530.0	530.0	529.5	528.0	526.9	525.5	529.2
11	1940	524.4	523.6	523.0	522.2	521.6	521.6	527.8	529.6	529.5	528.5	527.3	526.0	525.4
12	1941	524.5	524.5	524.6	524.3	524.6	524.4	524.8	524.5	523.4	522.1	520.5	518.9	523.4
13	1942	517.6	516.7	516.0	515.7	515.1	518.9	519.7	519.6	519.3	518.6	516.9	515.6	517.5
14	1943	514.6	514.9	515.3	515.3	515.5	518.0	519.7	522.1	521.2	520.0	518.6	517.2	517.7
15	1944	516.5	517.0	516.3	515.3	514.5	515.7	517.7	517.5	518.7	517.9	516.2	515.8	516.6
16	1945	514.7	514.2	514.2	514.3	514.3	517.6	519.5	521.6	522.5	522.4	521.4	520.2	518.1
17	1946	519.3	518.9	519.2	520.1	520.3	523.0	523.6	524.4	524.9	523.8	522.8	521.9	521.8
18	1947	521.4	520.5	520.0	520.1	521.0	522.8	525.0	526.2	525.1	524.2	522.6	521.2	522.5
19	1948	519.7	519.5	518.8	518.1	517.8	521.5	523.2	525.2	526.9	526.5	525.1	523.4	522.1
20	1949	522.0	522.1	521.6	523.0	523.9	525.1	525.7	525.6	524.1	522.4	520.7	519.4	523.0
21	1950	518.1	517.0	516.6	517.1	517.2	518.3	520.3	520.3	519.6	518.1	516.5	515.1	517.9
22	1951	513.5	513.6	514.0	514.3	516.9	519.1	521.2	521.3	520.5	519.5	518.8	517.6	517.5
23	1952	517.2	519.3	520.9	523.3	524.4	525.4	527.5	527.9	527.3	526.0	525.1	524.0	524.0
24	1953	522.5	521.5	521.4	522.7	524.6	528.2	530.0	530.0	529.4	528.0	526.3	524.7	525.8
25	1954	523.8	523.4	525.0	524.8	525.1	526.6	528.5	529.8	528.3	527.4	526.4	527.8	526.4
26	1955	527.3	528.8	530.0	529.3	529.4	530.0	530.0	529.2	528.5	527.4	528.6	528.0	528.9
27	1956	530.0	530.0	530.0	530.0	530.0	530.0	530.0	530.0	530.0	528.7	527.4	526.5	529.4
28	1957	525.4	525.1	525.5	525.8	525.7	526.8	527.9	527.2	526.3	524.7	523.0	521.4	525.4
29	1958	520.1	519.4	520.8	522.0	522.1	523.7	528.3	529.9	529.2	528.5	527.7	527.0	524.9
30	1959	526.2	526.0	526.0	526.3	526.1	527.7	530.0	529.5	528.8	528.6	527.9	526.7	527.5
31	1960	527.5	528.8	530.0	530.0	530.0	529.7	530.0	530.0	529.5	528.8	528.0	527.9	529.2
32	1961	527.4	527.5	527.4	526.9	527.1	529.2	530.0	530.0	530.0	529.0	527.9	526.8	528.3
33	1962	525.7	525.4	524.9	525.3	525.1	525.8	528.9	529.4	528.5	527.4	526.0	524.8	526.5
34	1963	524.8	524.7	524.8	524.3	523.9	525.2	527.4	527.1	526.2	524.5	522.8	521.6	524.8
35	1964	519.9	519.5	519.1	519.5	519.4	521.6	523.5	522.5	521.1	519.4	517.7	515.9	519.9
36	1965	514.3	512.9	512.1	511.0	510.3	510.0	510.8	509.8	508.4	506.2	504.2	502.5	509.4
37	1966	501.0	499.7	498.2	496.9	496.4	498.2	498.0	497.7	496.0	494.0	491.4	490.3	496.5
38	1967	490.0	490.0	490.0	490.0	490.0	490.0	495.3	498.9	499.1	498.1	496.4	494.6	493.5
39	1968	493.0	492.2	493.0	492.4	492.1	497.3	498.9	499.1	500.7	499.1	496.7	494.4	495.7
40	1969	492.4	491.6	491.9	491.0	490.6	491.6	497.0	497.9	496.5	494.4	493.4	491.9	493.3
41	1970	490.5	490.9	492.0	491.5	495.0	496.6	500.8	502.0	501.6	499.7	497.7	495.8	496.2
42	1971	494.1	493.1	492.3	491.1	490.8	491.7	495.4	496.6	494.8	492.9	491.2	490.2	492.9
43	1972	490.0	490.0	490.8	491.4	490.9	495.6	500.5	503.5	505.7	505.9	504.3	502.6	497.6
44	1973	501.4	502.5	505.1	507.5	509.4	512.6	515.6	517.5	517.4	517.1	515.7	514.5	511.4
45	1974	513.2	512.3	515.6	517.2	518.2	519.9	520.9	521.6	520.4	519.0	517.4	517.3	517.8
46	1975	516.9	516.9	518.1	519.1	519.7	521.8	523.8	523.1	522.6	521.7	520.7	520.9	520.4
47	1976	522.9	525.2	526.5	528.1	530.0	530.0	530.0	530.0	528.2	527.2	526.4	525.1	527.4
48	1977	524.2	523.1	522.4	521.5	520.7	524.3	526.6	527.8	527.1	525.7	524.7	524.1	524.3
49	1978	525.2	525.9	528.0	530.0	530.0	530.0	530.0	530.0	529.8	528.6	528.0	526.5	528.5
50	1979	525.5	524.4	523.9	527.4	528.2	530.0	530.0	530.0	529.1	528.2	528.0	528.0	527.7
	AVER	517.1	516.9	517.2	517.5	517.7	519.4	521.3	521.8	521.3	520.1	518.9	517.8	518.9

TABLE 6.11-8 ELEVATION OF QUABBIN WITH MILLERS

RUN V-25 7/06/83 MILLER/TULLY ALTER., DM=12, DT=0 NTS = 2 NTTS = 2 TYIELD = 335. MGD

23 2 2 2 1 1 1 2 QUABBIN RESERVOIR END-OF-MONTH ELEV (BOSTON CITY BASE)

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
													527.1	
1	1930	525.7	524.6	523.7	522.8	522.4	522.8	522.6	521.7	520.6	519.7	517.8	516.2	521.7
2	1931	514.7	513.4	512.1	510.8	509.7	510.9	515.1	516.4	517.2	515.8	514.9	513.2	513.7
3	1932	511.9	510.5	510.1	512.0	511.9	512.2	515.8	515.1	513.4	511.6	509.7	508.4	511.9
4	1933	509.0	511.1	510.4	510.5	511.4	513.0	520.3	520.7	519.4	517.6	516.2	517.2	514.8
5	1934	517.3	516.7	516.2	516.5	516.0	518.8	523.5	525.1	524.6	523.0	521.3	521.4	520.0
6	1935	521.0	521.0	522.1	524.2	524.1	527.3	529.1	528.7	528.4	527.6	525.8	524.7	525.4
7	1936	523.2	522.5	521.6	522.2	521.7	530.0	530.0	530.0	528.9	527.6	526.1	524.8	525.7
8	1937	524.3	523.5	526.5	530.0	530.0	529.9	530.0	530.0	529.2	528.0	527.1	526.2	527.9
9	1938	525.4	527.0	528.7	529.4	530.0	530.0	530.0	529.9	529.8	530.0	529.9	530.0	529.2
10	1939	530.0	530.0	530.0	529.6	529.9	530.0	530.0	530.0	529.0	527.6	526.1	524.5	528.9
11	1940	523.3	522.3	521.6	520.6	519.9	519.8	528.5	530.0	530.0	528.8	527.5	526.0	524.9
12	1941	524.4	524.3	524.4	524.2	524.4	524.1	524.3	523.9	522.7	521.2	519.4	517.6	522.9
13	1942	516.2	515.2	514.3	513.7	512.8	518.9	519.6	519.2	518.9	518.0	516.3	514.7	516.5
14	1943	513.4	513.6	514.3	514.1	514.4	517.9	519.8	523.9	522.5	521.1	519.6	518.0	517.7
15	1944	517.2	517.7	516.8	515.6	514.7	516.3	518.7	518.3	520.1	519.1	517.2	516.6	517.4
16	1945	515.5	514.9	514.7	514.9	514.7	519.9	522.0	525.8	526.6	526.4	525.4	524.0	520.4
17	1946	522.9	522.5	522.9	524.0	524.1	528.3	528.4	529.9	530.0	528.7	528.0	527.0	526.4
18	1947	526.5	525.5	524.8	524.8	525.9	528.5	530.0	530.0	528.5	527.8	526.2	524.6	526.9
19	1948	523.0	522.7	521.9	521.0	520.5	525.7	527.9	530.0	530.0	529.9	528.3	527.0	525.6
20	1949	525.4	525.4	524.8	527.0	527.9	529.2	529.7	529.7	528.0	526.2	524.3	523.0	526.7
21	1950	521.5	520.3	519.8	520.3	520.3	521.6	523.8	523.6	522.9	521.2	519.4	517.8	521.0
22	1951	516.3	516.7	517.8	518.0	521.0	524.1	526.6	526.2	525.3	524.2	523.3	522.0	521.8
23	1952	521.4	524.3	525.9	528.3	529.5	530.0	530.0	530.0	529.2	528.0	527.1	525.9	527.5
24	1953	524.3	523.1	523.1	524.9	527.2	530.0	530.0	530.0	529.1	527.7	525.7	523.9	526.6
25	1954	522.9	522.3	524.4	524.1	524.6	526.7	528.4	530.0	528.5	527.4	526.3	528.3	526.2
26	1955	527.7	529.8	530.0	529.3	529.1	530.0	530.0	529.6	528.4	527.1	528.2	527.5	528.9
27	1956	530.0	530.0	529.5	530.0	529.9	530.0	530.0	530.0	530.0	528.5	527.1	526.1	529.3
28	1957	524.8	524.4	524.7	525.0	524.8	526.1	526.9	526.1	525.1	523.2	521.3	519.7	524.4
29	1958	518.2	517.4	519.4	521.0	520.9	522.7	528.5	530.0	528.8	528.0	527.0	526.1	524.0
30	1959	525.2	525.0	524.7	525.2	524.9	526.7	530.0	529.4	528.5	528.2	527.3	526.0	526.7
31	1960	527.0	528.8	530.0	530.0	530.0	529.6	530.0	530.0	529.3	528.4	527.5	527.5	529.0
32	1961	527.0	527.0	526.8	526.2	526.5	529.4	530.0	530.0	529.5	528.3	527.1	525.9	527.8
33	1962	524.6	524.1	523.5	523.8	523.4	524.2	528.5	529.2	528.0	526.7	525.2	523.7	525.4
34	1963	523.8	523.6	523.8	523.2	522.7	524.3	527.2	526.8	525.7	523.8	522.0	520.6	524.0
35	1964	518.8	518.3	517.7	518.4	518.1	521.4	523.5	522.3	520.7	518.8	516.9	515.1	519.2
36	1965	513.1	511.5	510.6	509.4	508.5	508.1	508.7	507.5	506.0	503.6	501.4	499.3	507.3
37	1966	497.4	495.6	494.0	492.5	491.8	494.3	493.9	492.6	491.7	490.1	489.9	490.0	492.9
38	1967	490.0	490.0	490.0	490.0	490.0	490.0	496.7	502.3	502.2	501.1	499.4	497.5	494.9
39	1968	495.6	494.6	495.7	494.9	494.4	501.3	502.8	502.9	504.9	503.5	501.3	499.0	499.2
40	1969	496.8	495.8	496.8	495.6	494.9	496.5	503.3	504.4	503.1	501.1	500.6	499.0	499.0
41	1970	497.0	498.1	499.8	499.2	503.6	504.9	509.6	511.1	510.5	508.4	506.6	504.9	504.5
42	1971	503.3	502.3	501.5	500.4	499.8	500.6	504.6	506.2	504.3	502.5	501.0	499.4	502.2
43	1972	497.7	496.7	497.9	498.3	497.6	503.2	508.9	513.6	516.4	515.9	514.3	512.4	506.1
44	1973	511.0	512.2	515.8	518.7	520.9	525.4	528.4	530.0	529.0	529.1	528.0	526.7	522.9
45	1974	525.6	524.7	528.8	530.0	530.0	530.0	530.0	530.0	528.4	527.3	525.6	525.4	528.0
46	1975	524.8	524.7	526.1	526.8	527.6	530.0	530.0	528.7	528.2	527.5	526.5	527.1	527.3
47	1976	529.5	530.0	530.0	530.0	530.0	530.0	530.0	530.0	528.0	526.6	526.0	524.5	528.7
48	1977	523.5	522.2	521.4	520.4	519.4	524.9	528.1	528.9	528.0	526.8	525.7	524.9	524.5
49	1978	526.2	527.1	530.0	530.0	530.0	530.0	530.0	530.0	529.5	528.0	527.1	525.3	528.6
50	1979	524.1	522.9	522.2	526.3	526.9	530.0	530.0	530.0	528.7	528.0	527.6	527.1	527.0
	AVER	518.4	518.1	518.5	518.8	518.9	521.0	523.1	523.6	522.9	521.7	520.4	519.3	520.4

TABLE 6.11-9 REDUCTION OF QUABBIN IN FEET
RUN V-25 7/06/83 MILLER/TULLY ALTER., DM=12, DT=0 DELTA VALUES

P3 2 -1 5 6 2 1 2 QUABBIN REDUC IN ELEV, NO MILLER/WITH MILLER DA=12 DT=0

NY	NYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	1.0	1.2	1.3	1.4	1.3	1.2	1.3	1.4	1.6	1.7	1.9	2.0	1.4
2	1931	2.2	2.6	2.9	3.1	3.3	3.0	1.9	1.7	1.5	1.7	1.8	2.2	2.3
3	1932	2.5	2.7	2.7	2.1	2.4	2.5	1.3	1.4	1.8	2.1	2.3	2.4	2.2
4	1933	2.6	2.3	2.7	2.8	2.8	3.0	0.7	0.8	1.0	1.2	1.4	1.4	1.9
5	1934	1.6	1.7	1.9	2.0	2.1	1.6	0.5	0.1	0.3	0.5	0.7	0.8	1.1
6	1935	0.9	1.0	0.6	0.0	0.1	-0.8	-0.8	-0.6	-0.4	-0.5	-0.3	-0.2	-0.1
7	1936	-0.0	0.1	0.2	0.3	0.4	-1.2	0.0	-0.1	0.4	0.4	0.7	0.9	0.2
8	1937	1.0	1.2	0.4	-0.7	0.0	0.0	0.0	0.0	-0.1	-0.0	0.2	0.3	0.2
9	1938	0.5	0.2	-0.3	-0.7	-0.4	-0.0	0.0	-0.2	0.1	0.0	-0.1	0.0	-0.1
10	1939	0.0	0.0	0.0	0.4	0.1	0.0	0.0	-0.0	0.5	0.4	0.8	1.0	0.3
11	1940	1.2	1.3	1.4	1.6	1.7	1.8	-0.7	-0.4	-0.5	-0.3	-0.1	0.0	0.6
12	1941	0.1	0.2	0.2	0.2	0.2	0.4	0.5	0.6	0.8	0.9	1.1	1.3	0.5
13	1942	1.4	1.5	1.8	2.0	2.2	-0.0	0.1	0.4	0.4	0.5	0.7	0.9	1.0
14	1943	1.2	1.2	1.0	1.2	1.1	0.0	-0.1	-1.8	-1.3	-1.1	-1.0	-0.8	-0.0
15	1944	-0.7	-0.6	-0.5	-0.4	-0.3	-0.6	-0.9	-0.9	-1.3	-1.2	-1.0	-0.9	-0.8
16	1945	-0.8	-0.7	-0.5	-0.5	-0.4	-2.3	-2.5	-4.2	-4.1	-4.1	-3.9	-3.8	-2.3
17	1946	-3.7	-3.6	-3.7	-3.9	-3.8	-5.3	-4.8	-5.5	-5.1	-5.0	-5.2	-5.2	-4.6
18	1947	-5.1	-5.0	-4.9	-4.7	-4.9	-5.7	-5.0	-3.8	-3.3	-3.6	-3.5	-3.4	-4.4
19	1948	-3.3	-3.2	-3.0	-2.9	-2.8	-4.2	-4.7	-4.8	-3.1	-3.4	-3.2	-3.5	-3.5
20	1949	-3.5	-3.4	-3.3	-4.0	-3.9	-4.0	-4.0	-4.1	-3.9	-3.8	-3.7	-3.5	-3.8
21	1950	-3.4	-3.3	-3.2	-3.2	-3.1	-3.2	-3.5	-3.3	-3.2	-3.1	-2.9	-2.7	-3.2
22	1951	-2.8	-3.1	-3.9	-3.7	-4.1	-4.9	-5.4	-4.9	-4.8	-4.6	-4.5	-4.3	-4.3
23	1952	-4.2	-5.0	-5.0	-4.9	-5.1	-4.6	-2.5	-2.1	-1.9	-2.0	-2.0	-1.9	-3.4
24	1953	-1.8	-1.6	-1.7	-2.1	-2.6	-1.8	0.0	0.0	0.3	0.3	0.6	0.8	-0.8
25	1954	1.0	1.1	0.6	0.7	0.5	-0.1	0.1	-0.2	-0.2	-0.0	0.2	-0.6	0.3
26	1955	-0.4	-0.9	0.0	-0.0	0.4	0.0	0.0	-0.4	0.1	0.3	0.3	0.5	-0.0
27	1956	0.0	0.0	0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.3	0.5	0.1
28	1957	0.6	0.7	0.9	0.8	0.9	0.7	1.0	1.1	1.2	1.5	1.6	1.8	1.1
29	1958	1.9	2.1	1.3	1.1	1.2	1.1	-0.2	-0.1	0.3	0.5	0.7	0.8	0.9
30	1959	0.9	1.1	1.2	1.1	1.2	1.0	0.0	0.1	0.3	0.4	0.6	0.7	0.7
31	1960	0.5	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.4	0.5	0.4	0.2
32	1961	0.5	0.5	0.6	0.7	0.6	-0.2	0.0	0.0	0.5	0.7	0.8	1.0	0.5
33	1962	1.1	1.3	1.5	1.6	1.7	1.6	0.4	0.2	0.5	0.7	0.9	1.0	1.0
34	1963	1.0	1.1	1.0	1.1	1.2	0.9	0.2	0.4	0.5	0.7	0.9	1.0	0.8
35	1964	1.2	1.2	1.4	1.1	1.2	0.3	0.0	0.3	0.4	0.6	0.7	0.9	0.8
36	1965	1.2	1.4	1.5	1.6	1.8	2.0	2.1	2.3	2.5	2.6	2.8	3.1	2.1
37	1966	3.6	4.0	4.2	4.5	4.7	3.9	4.1	4.1	4.3	4.0	1.6	0.3	3.6
38	1967	0.0	-0.0	0.0	0.0	0.0	-0.0	-1.3	-3.4	-3.1	-3.0	-3.0	-2.8	-1.4
39	1968	-2.6	-2.4	-2.7	-2.5	-2.3	-4.0	-3.9	-3.8	-4.3	-4.4	-4.6	-4.6	-3.5
40	1969	-4.4	-4.3	-4.8	-4.6	-4.2	-4.9	-6.4	-6.4	-6.6	-6.7	-7.1	-7.0	-5.6
41	1970	-6.5	-7.2	-7.8	-7.7	-8.6	-8.3	-8.8	-9.2	-9.0	-8.8	-8.9	-9.1	-8.3
42	1971	-9.2	-9.2	-9.2	-9.2	-9.0	-8.9	-9.2	-9.7	-9.5	-9.6	-9.7	-9.2	-9.3
43	1972	-7.7	-6.7	-7.0	-6.9	-6.7	-7.6	-8.4	-10.1	-10.7	-10.1	-10.0	-9.8	-8.5
44	1973	-9.6	-9.8	-10.7	-11.2	-11.5	-12.8	-12.7	-12.5	-11.7	-12.0	-12.3	-12.3	-11.6
45	1974	-12.4	-12.4	-13.2	-12.8	-11.8	-10.1	-9.1	-8.4	-8.0	-8.3	-8.2	-8.1	-10.2
46	1975	-7.9	-7.8	-8.0	-7.7	-7.8	-8.2	-6.2	-5.5	-5.6	-5.9	-5.8	-6.2	-6.9
47	1976	-6.6	-4.8	-3.5	-1.9	0.0	0.0	0.0	0.0	0.2	0.5	0.4	0.6	-1.3
48	1977	0.7	0.9	0.9	1.1	1.2	-0.7	-1.5	-1.1	-0.9	-1.1	-0.9	-0.8	-0.2
49	1978	-1.0	-1.1	-2.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.9	1.2	-0.1
50	1979	1.3	1.5	1.7	1.1	1.3	0.0	0.0	0.0	0.4	0.2	0.4	0.9	0.7
	AVER	-1.5	-1.5	-1.5	-1.5	-1.4	-1.8	-1.9	-1.9	-1.8	-1.7	-1.7	-1.6	-1.5

TABLE 6.11-10

RUN V-25 7/06/83 MILLER/TULLY ALTER., DM=12, DT=0 NTS = 1 NTTS = 2 TYIELD = 300. MGD

39 2 1 8 11 3 2 2 RESERVOIR OUTFLOW - QUABBIN, DELTA FROM LEGAL MIN.

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1931	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1932	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1933	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	1934	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	1935	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1936	0.0	0.0	0.0	0.0	0.0	0.0	281.42	0.0	0.0	0.0	0.0	0.0	23.13
8	1937	0.0	0.0	0.0	0.0	70.84	0.0	404.23	229.14	0.0	0.0	0.0	0.0	58.12
9	1938	0.0	0.0	0.0	0.0	0.0	0.0	289.26	0.0	0.0	277.16	0.0	1032.16	132.15
10	1939	130.37	216.68	497.56	3.14	14.62	509.31	854.32	0.0	0.0	0.0	0.0	0.0	186.00
11	1940	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	1941	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	1942	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	1943	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	1944	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	1945	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	1946	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1947	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	1948	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	1949	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	1950	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	1951	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	1952	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	1953	0.0	0.0	0.0	0.0	0.0	0.0	435.74	546.82	0.0	0.0	0.0	0.0	82.26
25	1954	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	1955	0.0	0.0	147.38	0.0	0.0	214.60	381.26	0.0	0.0	0.0	0.0	0.0	62.08
27	1956	139.67	669.81	0.0	210.73	16.54	274.04	1239.75	313.06	16.70	0.0	0.0	0.0	239.22
28	1957	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	1958	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	1959	0.0	0.0	0.0	0.0	0.0	0.0	82.18	0.0	0.0	0.0	0.0	0.0	6.75
31	1960	0.0	0.0	81.35	26.37	123.26	0.0	1159.12	280.57	0.0	0.0	0.0	0.0	137.70
32	1961	0.0	0.0	0.0	0.0	0.0	0.0	631.40	80.59	4.46	0.0	0.0	0.0	59.11
33	1962	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	1964	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	1965	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	1966	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	1967	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	1969	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	1973	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	1974	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46	1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47	1976	0.0	0.0	0.0	0.0	203.57	419.52	194.49	50.57	0.0	0.0	0.0	0.0	71.53
48	1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	1978	0.0	0.0	0.0	164.33	56.00	63.87	604.31	104.28	0.0	0.0	0.0	0.0	82.20
50	1979	0.0	0.0	0.0	0.0	0.0	577.94	523.16	185.77	0.0	0.0	0.0	0.0	107.86
	AVER	5.40	17.73	14.53	8.09	9.70	41.19	141.61	35.82	0.42	5.54	0.0	20.64	24.96

TABLE 6.11-11

RUN V-25 7/06/83 MILLER/TULLY ALTER., DM=12, DT=0 NTS = 2 NTTS = 2 TYIELD = 335. MGD

'39 2 2 8 11 3 2 2 RESERVOIR OUTFLOW - QUABBIN, DELTA FROM LEGAL MIN.

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1931	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1932	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1933	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	1934	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	1935	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1936	0.0	0.0	0.0	0.0	0.0	0.0	574.37	12.55	0.0	0.0	0.0	0.0	48.27
8	1937	0.0	0.0	0.0	0.0	200.23	0.0	404.23	193.35	0.0	0.0	0.0	0.0	65.05
9	1938	0.0	0.0	0.0	0.0	74.05	82.05	293.67	0.0	0.0	127.72	0.0	1066.60	135.30
10	1939	96.08	216.68	497.56	0.0	0.0	495.78	854.32	18.69	0.0	0.0	0.0	0.0	182.14
11	1940	0.0	0.0	0.0	0.0	0.0	0.0	0.0	63.06	0.0	0.0	0.0	0.0	5.36
12	1941	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	1942	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	1943	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	1944	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	1945	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	1946	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1947	0.0	0.0	0.0	0.0	0.0	0.0	145.79	205.46	0.0	0.0	0.0	0.0	29.43
19	1948	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	160.08	0.0	0.0	0.0	13.16
20	1949	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	1950	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	1951	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	1952	0.0	0.0	0.0	0.0	0.0	99.31	394.82	56.13	0.0	0.0	0.0	0.0	45.65
24	1953	0.0	0.0	0.0	0.0	0.0	147.90	899.52	546.82	0.0	0.0	0.0	0.0	132.94
25	1954	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	1955	0.0	0.0	267.84	0.0	0.0	121.64	288.74	0.0	0.0	0.0	0.0	0.0	56.81
27	1956	75.77	669.81	0.0	64.32	0.0	254.53	1239.75	279.12	0.0	0.0	0.0	0.0	214.17
28	1957	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	1958	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.78	0.0	0.0	0.0	0.0	0.15
30	1959	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	1960	0.0	0.0	71.83	11.62	123.26	0.0	1113.40	280.57	0.0	0.0	0.0	0.0	131.88
32	1961	0.0	0.0	0.0	0.0	0.0	0.0	683.58	80.59	0.0	0.0	0.0	0.0	63.03
33	1962	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	1964	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	1965	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	1966	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-57.00	-5.67	-5.31
38	1967	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	1969	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	1973	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.30	0.0	0.0	0.0	0.0	3.34
45	1974	0.0	0.0	0.0	67.53	202.90	278.37	226.36	117.99	0.0	0.0	0.0	0.0	73.57
46	1975	0.0	0.0	0.0	0.0	0.0	0.0	464.71	0.0	0.0	0.0	0.0	0.0	38.20
47	1976	0.0	420.15	324.15	390.26	730.96	308.08	126.56	9.81	0.0	0.0	0.0	0.0	188.68
48	1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	1978	0.0	0.0	0.0	650.10	14.94	43.40	604.31	104.28	0.0	0.0	0.0	0.0	118.57
50	1979	0.0	0.0	0.0	0.0	0.0	268.90	523.16	185.77	0.0	0.0	0.0	0.0	81.62
	AVER	3.44	26.13	23.23	23.68	26.93	42.00	176.75	43.92	3.20	2.55	-1.14	21.22	32.44

TABLE 6.11-12

RUN V-25 7/06/83 MILLER/TULLY ALTER., DM=12, DT=0 NTS = 2 NTTS = 2 TYIELD = 335. MGD

33 2 2 7 6 0 2 2 POTENTIAL TRANSFER POINT 6, MGD

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0.0	0.0	0.0	13.18	59.92	73.03	0.0	3.39	0.0	0.0	0.0	0.0	12.21
2	1931	0.0	0.0	0.0	0.0	0.0	77.01	160.71	110.54	87.14	0.0	0.0	0.0	36.30
3	1932	0.0	0.0	23.38	138.84	0.0	0.0	205.28	30.36	0.0	0.0	0.0	0.0	33.23
4	1933	0.0	55.20	0.0	0.0	0.0	0.0	479.26	31.78	0.0	0.0	0.16	23.70	48.59
5	1934	0.0	0.0	0.0	0.0	0.0	149.99	279.95	122.97	12.44	0.0	0.0	10.10	48.05
6	1935	0.0	7.55	128.72	177.52	0.0	232.68	8.61	49.44	26.39	4.15	0.0	0.0	53.82
7	1936	0.0	5.70	15.95	0.0	0.0	539.52	140.61	12.70	0.0	0.0	0.0	0.0	60.28
8	1937	0.0	0.0	210.78	337.21	108.71	0.0	36.52	222.14	64.30	2.03	0.0	0.0	82.21
9	1938	1.89	109.67	116.18	163.27	145.76	73.22	0.0	39.23	0.0	60.23	65.29	290.57	88.18
10	1939	10.27	6.32	280.77	0.0	0.0	81.48	185.75	47.58	0.0	0.0	0.0	0.0	51.47
11	1940	0.0	0.51	0.0	0.0	0.0	10.42	615.48	250.66	111.01	0.0	0.0	0.0	81.93
12	1941	0.0	20.46	40.53	37.53	20.07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.85
13	1942	0.0	0.0	8.63	4.34	0.0	454.49	0.0	3.34	42.64	0.0	0.0	0.0	43.49
14	1943	0.0	22.88	62.66	0.0	40.72	237.19	15.97	418.11	12.18	0.0	1.03	0.0	68.38
15	1944	3.25	20.14	0.0	0.0	0.0	115.31	90.47	44.98	156.27	0.0	0.0	0.0	35.83
16	1945	0.0	0.0	0.0	39.02	0.0	461.94	57.34	397.40	129.93	30.41	0.0	0.0	94.27
17	1946	0.0	10.76	58.91	86.51	0.0	398.39	0.0	173.63	123.29	0.0	0.0	0.0	71.95
18	1947	13.80	0.0	0.48	0.0	86.81	219.70	69.65	126.17	31.27	0.0	0.0	0.0	45.54
19	1948	0.0	5.02	0.0	0.0	0.0	338.50	163.08	268.29	87.98	0.0	0.0	0.0	72.58
20	1949	0.0	11.45	4.89	208.59	44.20	102.40	5.37	37.83	0.0	0.0	0.0	0.0	34.81
21	1950	0.0	0.0	17.74	43.42	0.0	63.75	58.31	28.21	15.09	0.0	0.0	0.45	19.08
22	1951	0.0	107.74	217.72	14.59	136.52	193.32	129.39	14.88	0.0	0.0	0.0	0.0	67.38
23	1952	1.92	202.50	82.15	174.32	102.42	116.58	130.50	96.65	80.96	0.0	0.0	0.0	81.94
24	1953	0.0	0.0	46.00	137.91	147.93	341.83	356.15	303.99	0.0	0.0	0.0	0.0	111.09
25	1954	0.0	0.0	157.75	0.0	95.30	149.10	58.82	298.02	25.90	0.36	0.0	218.25	83.61
26	1955	0.0	132.83	218.54	24.26	0.0	130.35	27.02	87.63	7.34	0.0	23.86	0.0	54.90
27	1956	118.09	282.61	0.0	145.51	0.0	0.0	353.16	345.18	31.27	0.0	0.0	0.0	106.53
28	1957	0.0	3.09	2.08	40.35	19.77	107.57	6.91	22.33	0.0	0.0	0.0	0.0	16.97
29	1958	0.0	0.0	203.90	100.97	0.0	27.31	311.34	253.26	0.0	0.0	0.0	0.0	75.31
30	1959	0.0	1.17	0.0	67.38	0.0	73.39	211.99	32.94	0.0	0.0	0.0	0.0	32.27
31	1960	95.63	115.01	351.08	109.71	48.25	17.09	560.07	146.94	18.37	0.0	0.0	70.14	127.65
32	1961	20.78	25.70	8.62	0.0	65.41	199.02	212.93	134.46	0.0	0.0	0.0	0.0	55.45
33	1962	0.0	0.0	0.0	0.0	0.0	45.55	296.03	73.82	0.0	0.0	0.0	0.0	34.47
34	1963	46.65	7.35	65.93	0.0	0.0	114.88	172.09	19.24	0.0	0.0	0.0	0.0	35.70
35	1964	0.0	13.04	0.0	104.30	0.0	259.42	57.83	8.57	0.0	0.0	0.0	0.0	37.44
36	1965	0.0	0.0	15.86	0.0	0.0	0.0	0.0	2.19	0.0	0.0	0.0	0.0	1.53
37	1966	0.0	0.0	0.0	0.0	0.0	156.26	0.0	27.37	0.0	0.0	0.0	0.0	15.60
38	1967	0.0	0.92	0.0	0.0	0.0	5.04	219.84	423.93	40.66	0.0	0.0	0.0	57.92
39	1968	0.0	0.0	75.89	0.0	0.0	325.38	73.31	49.21	172.82	32.96	0.0	0.0	61.29
40	1969	0.0	6.45	127.28	0.0	0.0	103.85	370.11	118.73	17.96	2.12	85.06	0.0	69.55
41	1970	0.0	118.38	109.75	13.81	301.12	61.83	216.57	143.98	0.0	0.0	0.0	0.0	78.60
42	1971	0.0	0.0	0.0	0.0	0.0	12.60	191.57	200.81	0.0	0.0	0.0	0.0	33.87
43	1972	0.0	0.0	6.25	0.0	0.0	265.10	314.75	349.40	172.97	0.80	0.0	0.0	92.88
44	1973	0.0	50.18	203.05	258.73	215.81	426.16	116.74	236.33	48.71	113.11	4.99	0.0	139.79
45	1974	0.0	0.0	319.45	220.07	127.10	177.95	8.22	139.32	16.51	0.0	0.0	0.0	84.55
46	1975	0.0	5.00	53.11	0.0	78.70	200.90	79.72	21.82	43.53	2.47	10.99	135.74	52.31
47	1976	250.13	207.59	99.74	112.27	477.25	356.12	74.83	147.11	0.0	1.92	63.32	0.0	147.36
48	1977	0.0	0.0	19.38	0.0	0.0	445.52	221.28	65.68	0.0	0.0	0.0	0.0	63.25
49	1978	90.55	38.11	202.95	310.46	77.27	103.86	127.31	43.63	18.10	0.0	0.0	0.0	84.83
50	1979	0.0	0.0	0.0	121.64	0.0	611.53	66.26	189.87	34.17	0.0	0.0	0.0	86.65
	AVER	13.06	31.87	71.12	64.11	47.98	173.13	150.74	128.32	32.58	5.01	5.09	14.98	61.65

TABLE 6.11-13
RUN V-25 7/06/83 MILLER/TULLY ALTER., DM=12, DT=0 NTS = 2 NTTS = 2 TYIELD = 335. MGD

34 2 2 6 6 0 2 2 ACTUAL TRANSFER POINT 6, MGD

NY	IYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0.0	0.0	0.0	13.18	59.92	73.03	0.0	3.39	0.0	0.0	0.0	0.0	12.21
2	1931	0.0	0.0	0.0	0.0	0.0	77.01	160.71	110.54	87.14	0.0	0.0	0.0	36.30
3	1932	0.0	0.0	23.38	138.84	0.0	0.0	205.28	30.36	0.0	0.0	0.0	0.0	33.23
4	1933	0.0	55.20	0.0	0.0	0.0	0.0	479.26	31.78	0.0	0.0	0.16	23.70	48.59
5	1934	0.0	0.0	0.0	0.0	0.0	149.99	279.95	122.97	12.44	0.0	0.0	10.10	48.05
6	1935	0.0	7.55	128.72	177.52	0.0	232.68	8.61	49.44	26.39	4.15	0.0	0.0	53.82
7	1936	0.0	5.70	15.95	0.0	0.0	388.06	0.0	0.0	0.0	0.0	0.0	0.0	34.78
8	1937	0.0	0.0	210.78	278.75	0.0	0.0	0.0	0.0	64.30	2.03	0.0	0.0	47.03
9	1938	1.89	109.67	116.18	163.27	0.0	0.0	0.0	39.23	0.0	0.0	65.29	0.0	41.79
10	1939	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	1940	0.0	0.51	0.0	0.0	0.0	10.42	615.48	0.0	80.92	0.0	0.0	0.0	58.16
12	1941	0.0	20.46	40.53	37.53	20.07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.85
13	1942	0.0	0.0	8.63	4.34	0.0	454.49	0.0	3.34	42.64	0.0	0.0	0.0	43.49
14	1943	0.0	22.88	62.66	0.0	40.72	237.19	15.97	418.11	12.18	0.0	1.03	0.0	68.38
15	1944	3.25	20.14	0.0	0.0	0.0	115.31	90.47	44.98	156.27	0.0	0.0	0.0	35.83
16	1945	0.0	0.0	0.0	39.02	0.0	461.94	57.34	397.40	129.93	30.41	0.0	0.0	94.27
17	1946	0.0	10.76	58.91	86.51	0.0	398.39	0.0	173.63	27.95	0.0	0.0	0.0	64.11
18	1947	13.80	0.0	0.48	0.0	86.81	219.70	0.0	0.0	31.27	0.0	0.0	0.0	29.10
19	1948	0.0	5.02	0.0	0.0	0.0	338.50	163.08	116.96	0.0	0.0	0.0	0.0	52.49
20	1949	0.0	11.45	4.89	208.59	44.20	102.40	5.37	37.83	0.0	0.0	0.0	0.0	34.81
21	1950	0.0	0.0	17.74	43.42	0.0	63.75	58.31	28.21	15.09	0.0	0.0	0.45	19.08
22	1951	0.0	107.74	217.72	14.59	136.52	193.32	129.39	14.88	0.0	0.0	0.0	0.0	67.38
23	1952	1.92	202.50	82.15	174.32	102.42	0.0	0.0	0.0	80.96	0.0	0.0	0.0	53.10
24	1953	0.0	0.0	46.00	137.91	147.93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.97
25	1954	0.0	0.0	157.75	0.0	95.30	149.10	58.82	79.53	25.90	0.36	0.0	218.25	65.06
26	1955	0.0	132.83	0.0	24.26	0.0	0.0	0.0	87.63	7.34	0.0	23.86	0.0	23.05
27	1956	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.03	0.0	0.0	0.0	1.65
28	1957	0.0	3.09	2.08	40.35	19.77	107.57	6.91	22.33	0.0	0.0	0.0	0.0	16.97
29	1958	0.0	0.0	203.90	100.97	0.0	27.31	311.34	0.0	0.0	0.0	0.0	0.0	53.80
30	1959	0.0	1.17	0.0	67.38	0.0	73.39	180.72	32.94	0.0	0.0	0.0	0.0	29.70
31	1960	95.63	115.01	0.0	0.0	0.0	17.09	0.0	0.0	18.37	0.0	0.0	70.14	26.30
32	1961	20.78	25.70	8.62	0.0	65.41	199.02	0.0	0.0	0.0	0.0	0.0	0.0	26.53
33	1962	0.0	0.0	0.0	0.0	0.0	45.55	296.03	73.82	0.0	0.0	0.0	0.0	34.47
34	1963	46.65	7.35	65.93	0.0	0.0	114.88	172.09	19.24	0.0	0.0	0.0	0.0	35.70
35	1964	0.0	13.04	0.0	104.30	0.0	259.42	57.83	8.57	0.0	0.0	0.0	0.0	37.44
36	1965	0.0	0.0	15.86	0.0	0.0	0.0	0.0	2.19	0.0	0.0	0.0	0.0	1.53
37	1966	0.0	0.0	0.0	0.0	0.0	156.26	0.0	27.37	0.0	0.0	0.0	0.0	15.60
38	1967	0.0	0.92	0.0	0.0	0.0	5.04	219.84	423.93	40.66	0.0	0.0	0.0	57.92
39	1968	0.0	0.0	75.89	0.0	0.0	325.38	73.31	49.21	172.82	32.96	0.0	0.0	61.29
40	1969	0.0	6.45	127.28	0.0	0.0	103.85	370.11	118.73	17.96	2.12	85.06	0.0	69.55
41	1970	0.0	118.38	109.75	13.81	301.12	61.83	216.57	143.98	0.0	0.0	0.0	0.0	78.60
42	1971	0.0	0.0	0.0	0.0	0.0	12.60	191.57	200.81	0.0	0.0	0.0	0.0	33.87
43	1972	0.0	0.0	6.25	0.0	0.0	265.10	314.75	349.40	172.97	0.80	0.0	0.0	92.88
44	1973	0.0	50.18	203.05	258.73	215.81	426.16	116.74	0.0	48.71	113.11	4.99	0.0	119.72
45	1974	0.0	0.0	319.45	0.0	0.0	0.0	0.0	0.0	16.51	0.0	0.0	0.0	28.49
46	1975	0.0	5.00	53.11	0.0	78.70	105.18	0.0	21.82	43.53	2.47	10.99	135.74	37.62
47	1976	250.13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.92	63.32	0.0	26.78
48	1977	0.0	0.0	19.38	0.0	0.0	445.52	221.28	65.68	0.0	0.0	0.0	0.0	63.25
49	1978	90.55	38.11	202.95	0.0	0.0	0.0	0.0	0.0	18.10	0.0	0.0	0.0	29.55
50	1979	0.0	0.0	0.0	121.64	0.0	0.0	0.0	0.0	34.17	0.0	0.0	0.0	13.14
	AVER	10.49	21.94	52.12	44.98	28.29	128.33	101.54	67.00	28.09	3.81	5.09	9.17	41.87

TABLE 6.11-14

RUN V-25 7/06/83 MILLER/TULLY ALTER., DM=12, DT=0 NTS = 2 NTTS = 2 TYIELD = 335. MGD

35 2 2 9 6 0 0 2 POTENTIAL MINUS ACTUAL TRANSFER - POINT 6, MGD

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1931	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1932	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1933	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1934	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1935	0	0	0	0	0	0	0	0	0	0	0	0	0
7	1936	0	0	0	0	0	151	141	13	0	0	0	0	25
8	1937	0	0	0	58	109	0	37	222	0	0	0	0	35
9	1938	0	0	0	0	146	73	0	0	0	60	0	291	46
10	1939	10	6	281	0	0	81	186	48	0	0	0	0	51
11	1940	0	0	0	0	0	0	0	251	30	0	0	0	24
12	1941	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1942	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1943	0	0	0	0	0	0	0	0	0	0	0	0	0
15	1944	0	0	0	0	0	0	0	0	0	0	0	0	0
16	1945	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1946	0	0	0	0	0	0	0	0	95	0	0	0	8
18	1947	0	0	0	0	0	0	70	126	0	0	0	0	16
19	1948	0	0	0	0	0	0	0	151	88	0	0	0	20
20	1949	0	0	0	0	0	0	0	0	0	0	0	0	0
21	1950	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1951	0	0	0	0	0	0	0	0	0	0	0	0	0
23	1952	0	0	0	0	0	117	130	97	0	0	0	0	29
24	1953	0	0	0	0	0	342	356	304	0	0	0	0	84
25	1954	0	0	0	0	0	0	0	218	0	0	0	0	19
26	1955	0	0	219	0	0	130	27	0	0	0	0	0	32
27	1956	118	283	0	146	0	0	353	345	11	0	0	0	105
28	1957	0	0	0	0	0	0	0	0	0	0	0	0	0
29	1958	0	0	0	0	0	0	0	253	0	0	0	0	22
30	1959	0	0	0	0	0	0	31	0	0	0	0	0	3
31	1960	0	0	351	110	48	0	560	147	0	0	0	0	101
32	1961	0	0	0	0	0	0	213	134	0	0	0	0	29
33	1962	0	0	0	0	0	0	0	0	0	0	0	0	0
34	1963	0	0	0	0	0	0	0	0	0	0	0	0	0
35	1964	0	0	0	0	0	0	0	0	0	0	0	0	0
36	1965	0	0	0	0	0	0	0	0	0	0	0	0	0
37	1966	0	0	0	0	0	0	0	0	0	0	0	0	0
38	1967	0	0	0	0	0	0	0	0	0	0	0	0	0
39	1968	0	0	0	0	0	0	0	0	0	0	0	0	0
40	1969	0	0	0	0	0	0	0	0	0	0	0	0	0
41	1970	0	0	0	0	0	0	0	0	0	0	0	0	0
42	1971	0	0	0	0	0	0	0	0	0	0	0	0	0
43	1972	0	0	0	0	0	0	0	0	0	0	0	0	0
44	1973	0	0	0	0	0	0	0	236	0	0	0	0	20
45	1974	0	0	0	220	127	178	8	139	0	0	0	0	56
46	1975	0	0	0	0	0	96	80	0	0	0	0	0	15
47	1976	0	208	100	112	477	356	75	147	0	0	0	0	121
48	1977	0	0	0	0	0	0	0	0	0	0	0	0	0
49	1978	0	0	0	310	77	104	127	44	0	0	0	0	55
50	1979	0	0	0	0	0	612	66	190	0	0	0	0	74
	AVER	3	10	19	19	20	45	49	61	4	1	0	6	20

TABLE 6.11-15

SAFE YIELD ANALYSES FOR MILLERS PLUS TULLY
(DM=12, DT=8)

Run	Trial Yield (MGD)	Actual Yield (MGD)	Reliability Percentage	Number of Monthly Failures	AT(6) (MGD)	AT(6) Percentage of PT(6)	QO(11) (MGD)
V-11	333	330.9	98.50	8	46.4	63.0	67.9
V-15	338	335.3	98.50	8	48.0	65.2	64.8
V-15	339	336.3	98.50	8	48.1	65.4	64.0
V-15	340	337.2	98.34	9	48.2	65.4	63.4
V-12	341	338.1	98.34	9	48.7	66.0	62.6
V-12	342	338.9	98.34	9	49.0	66.6	62.2
V-12	343	339.8	98.34	9	49.5	67.2	61.9
V-12	344	340.7	98.34	9	49.9	67.8	61.6
V-11	345	341.6	98.34	9	50.3	68.3	61.1

The analysis shows that although the potential transfer increases 12.02 MGD, the actual transfer increases only 6.27 MGD, and the safe yield only 4 MGD. The Millers Plus Tully option exhibits the same sensitivity to changes in the safe yield reliability as did the Millers-alone option. As can be seen in Table 6.11-15, the number of failures is the same for both 333 MGD and 339 MGD. If nine rather than eight failures were to be adopted, the safe yield would increase from 339 to at least 345 MGD.

ADDITIONAL ANALYSES--MILLERS PLUS TULLY

Run V-27 used a tunnel diameter of 13 feet in lieu of 12 feet for the Athol-to-Quabbin tunnel. The Tully-to-Athol tunnel remained at 8 feet. This change increases the mean potential transfer from 73.67 to 76.43 MGD, and the actual transfer from 48.14 to 49.52 MGD. The safe yield increases from 339.01 to 340.01 MGD.

SENSITIVITY RUNS--QUABBIN MINIMUM POOL

Runs V-28 and V-29 were made to test the sensitivity of the alternative to a reduction in the Quabbin minimum pool level. Tunnel diameters of 13 and 8 feet were used, and the Quabbin minimum pool was reduced from elevation 490 to 480.

The safe yield for the sensitivity runs (8 monthly failures) is 361.01 MGD. Although the complete range of trial yields that would cause either eight or nine monthly failures was not explored, there is a considerable spread, similar to the results found for previous analyses.

SAFE YIELD FOR PLANNING PURPOSES

The incremental safe yields (system safe yields above 300 MGD) for the Millers alternative scenarios that were analyzed are as follows:

	Scenario	DM ft	DT ft	PT(6) MGD	AT(6) MGD	Incremental Safe Yield MGD
1	Millers Alone*	10	0	54.9	39.0	33.0
2	Millers Alone	11	0	59.0	40.7	34.0
3	Millers Alone	12	0	61.7	41.9	35.0
4	Millers Alone	13	0	63.2	42.3	35.0
5	Millers Plus Tully*	10	8	62.7	43.2	36.0
6	Millers Plus Tully	11	8	69.3	46.0	38.0
7	Millers Plus Tully	12	8	73.7	48.1	39.0
8	Millers Plus Tully	13	8	76.4	49.5	40.0

*Selected for Engineering Analysis; see Section 6.12.

The incremental safe yields, i.e., the amounts that the safe yield of the existing system (without Sudbury) would increase as a result of adding one of the Millers scenarios, are highly sensitive to the reliability used to define the safe yield, and probably to other system variables as well. Consequently, it is believed that the results shown should be adopted only for planning purposes at this time for the reasons that follow; subsequent analysis of measures to minimize harm may refine the final planning value of safe yield for this alternative.

The reliability used to define safe yield, given as program input data, was 98.5 percent (read as 98.5000). This was based on the reliability associated with a safe yield of 300 MGD (8 monthly failures) for the existing system (without Sudbury), the justification for which is given in the report Task 4: Safe Yield - Existing System. The reliabilities in the range of interest, when calculated to greater precision, are as follows (trial yields apply to the DM=12, DT=0 scenario):

Number of Monthly Failures	Reliability (percentage)	Trial Yield (MGD)
7	98.6689	324 to 328
8	98.5025	329 to 335
(8) Safe Yield	98.5000	335.01
9	98.3361	336 to 340+

Because the input value for safe yield reliability was rounded to a slightly lower value than 98.5025, the program used the highest trial yield having eight failures as the safe yield, obtaining a value of 335.01 MGD. If the input value for the safe yield reliability had been selected to be 98.5030, the safe yield would have been calculated as 328.99 MGD, a difference of 6 MGD as a result of a reliability change of only 0.003 percent!

This extreme sensitivity of the safe yield to minor changes in the value of the reliability used to define safe yield must be kept in mind when relating the incremental safe yield of the Millers Alternative to the incremental safe yield of other alternatives. It is also entirely possible that some fine tuning of the algorithms used in the safe yield model, particularly the operating rules for Quabbin and Wachusett Reservoirs, could result in an increase of about 5 MGD in the incremental safe yield.

HYDROLOGIC IMPACTS (MILLERS WITHOUT TULLY)

The safe yield model was used to evaluate streamflow and other hydrologic impacts for the Millers-Without-Tully alternative. The run number, HY-12 dated 06/19/85, applies to a 10-foot diameter tunnel from Athol to Quabbin Reservoir. Two trials were made, the first with the alternative inactive and a trial yield of 300 MGD (safe yield) to establish baseline data, and the second with the alternative active and a trial yield of 333 MGD (safe yield, Millers-Without-Tully). Summary data for the first trial are shown in Table 6.11-16 and in Table 6.11-17 for the second trial. The mean values for key parameters are shown in Table 6.11-18.

The general hydrologic impact can be summarized as follows:

(1) 38 MGD (50-year mean value) is transferred from the Millers River to Quabbin Reservoir, with a reduction in flow of the same amount in the downstream reaches of the Millers River and the Connecticut River to its confluence with the Chicopee River.

(2) Of the 38 MGD of extra inflow to Quabbin, 31 MGD is transferred to Wachusett and 7 MGD is added to the spill to the Swift River, thereby increasing the flows in the Swift River and Chicopee River by 7 MGD.

(3) The flows in the Connecticut River below the confluence with the Chicopee River are reduced by 31 MGD.

(4) The outflow from Wachusett Reservoir is decreased by 1 MGD (from 4.9 to 3.9 MGD), and this reduction extends downstream along the Nashua and Merrimack Rivers.

The 50-year mean values of system parameters are only useful to show comparative trends between alternatives, and monthly values must be examined to obtain a better sense of potential impacts. Brief discussion of selected parameters follows.

(1) Table 6.11-19 Quabbin Reservoir End-of-Month Storage, Percent of Net Storage (differences, chronological). In general, the Millers alternative causes Quabbin to have more active storage (from 10 to 28 percent) during wet periods, and less storage (from 3 to 7 percent) during dry periods.

(2) Table 6.11-20 Quabbin Reservoir End-of-Month Elevations (differences, sorted). On average, the elevation of Quabbin is one-foot higher with the alternative.

Table 6.11-16: SUMMARY OUTPUT FOR TRIAL NO. 1

RUN HY-12 06/19/85 MILLERS ALTERNATIVE (WITHOUT TULLY) DM=10, DT=0 NMFAIL = 8 0 0 8 NTTS= 2 TYIELD= 300. MGD

TOTAL TRANSFERS MGD	SHAFT 8 TO QUABBIN	SHAFT 8 TO WACH	QUABBIN TO WACH	WACH TO MARL TUN	NORTHF TO QUABBIN	MILLERS TO QUABBIN	WACH TO SUDBURY	SUDBURY TO BOSTON	MERRIMACK TO BOSTON	PLYMOUTH TO BOSTON	LOCALS TO SYSTEM	FRAM TO SUDBURY
POTENTIAL =	44.06	0.28	396.71	273.46	0.0	0.0	2.00	0.0	0.0	0.0	0.0	0.0
ACTUAL =	43.46	0.88	167.17	271.82	0.0	0.0	2.00	0.0	0.0	0.0	0.0	0.0
PCT =	98.64	313.75	42.14	99.40	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0

	QUABBIN	WACHUSETT	SUDBURY	FRAMINGHAM	FRAM#1	FRAM#2	FRAM#3
MEAN RESERVOIR ELEVATION - FT BCB	518.93	390.47	260.00	177.58	0.0	0.0	0.0
WATER BALANCE - MGD							
1 WATERSHED INFLOW	164.38	119.11	20.23	53.03			
2 PRECIP ON RESERVOIRS	73.40	13.56	4.31	1.77			
3 EVAPORATION LOSS	-45.12	-8.14	-2.64	-1.08			
4 SEEPAGE LOSS	0.0	-0.93	0.0	0.0			
5 OUTFLOW TO STREAM	-55.35	-4.91	-23.90	-77.61			
6 CONDUIT TRANSFER IN	43.46	168.05	2.00	23.90			
7 CONDUIT TRANSFER OUT	-167.17	-273.82	0.0	0.0			
8 DIRECT WITHDRAWAL	-13.60	-12.92	0.0	0.0			
11 RESERVOIR YIELD-MGD	192.66	123.60	21.90	53.72			
RESERVOIR YIELD-MGD/SM	1.04	1.15	1.00	1.01			

INTERBASIN TRANSFERS - MGD

CONNECTICUT TO NASHUA	168.05
NASHUA TO SUDBURY RESERVOIR	2.00
NASHUA TO SUDBURY & BOSTON	91.57
WEST TO SUDBURY & BOSTON	259.62
SUDBURY TO BOSTON	0.0

SYSTEM ACTUAL YIELD - MGD

FRAM./BOSTON	259.62
WEST	38.73
TOTAL	298.35

Table 6.11-17: SUMMARY OUTPUT FOR TRIAL NO. 2

RUN HY-12 06/19/85 MILLERS ALTERNATIVE (WITHOUT TULLY) DM=10, DT=0 NMFAIL = 8 1 1 8 NTTS= 2 TYIELD= 333. MGD

TOTAL TRANSFERS MGD	SHAFT 8 TO QUABBIN	SHAFT 8 TO WACH	QUABBIN TO WACH	WACH TO MARL TUN	NORTHF TO QUABBIN	MILLERS TO QUABBIN	WACH TO SUDBURY	SUDBURY TO BOSTON	MERRIMACK TO BOSTON	PLYMOUTH TO BOSTON	LOCALS TO SYSTEM	FRAM TO SUDBURY
POTENTIAL =	44.07	0.28	398.27	306.46	0.0	54.85	2.00	0.0	0.0	0.0	0.0	0.0
ACTUAL =	42.19	2.15	196.89	303.86	0.0	38.10	2.00	0.0	0.0	0.0	0.0	0.0
PCT =	95.74	780.08	49.44	99.15	0.0	69.46	100.00	0.0	0.0	0.0	0.0	0.0

	QUABBIN	WACHUSETT	SUDBURY	FRAMINGHAM	FRAM#1	FRAM#2	FRAM#3
MEAN RESERVOIR ELEVATION - FT BCB	520.12	390.25	260.00	177.58	0.0	0.0	0.0
WATER BALANCE - MGD							
1 WATERSHED INFLOW	163.79	119.14	20.23	53.03			
2 PRECIP ON RESERVOIRS	74.49	13.52	4.31	1.77			
3 EVAPORATION LOSS	-45.78	-8.12	-2.64	-1.08			
4 SEEPAGE LOSS	0.0	-0.92	0.0	0.0			
5 OUTFLOW TO STREAM	-62.34	-3.90	-23.90	-77.61			
6 CONDUIT TRANSFER IN	80.29	199.04	2.00	23.90			
7 CONDUIT TRANSFER OUT	-196.89	-305.86	0.0	0.0			
8 DIRECT WITHDRAWAL	-13.57	-12.91	0.0	0.0			
11 RESERVOIR YIELD-MGD	192.50	123.62	21.90	53.72			
RESERVOIR YIELD-MGD/SM	1.04	1.15	1.00	1.01			

INTERBASIN TRANSFERS - MGD

CONNECTICUT TO NASHUA	199.04
NASHUA TO SUDBURY RESERVOIR	2.00
NASHUA TO SUDBURY & BOSTON	92.61
WEST TO SUDBURY & BOSTON	291:66
SUDBURY TO BOSTON	0.0

SYSTEM ACTUAL YIELD - MGD

FRAM./BOSTON	291.66
WEST	38.68
TOTAL	330.33

Table 6.11-18: Summary of Hydrologic Impacts Millers Without Tully Alternative, Run No. HY-12

(Units in MGD except as noted)
(Values are mean for 50 years)

	Baseline	With Alternative	Difference	Percent Difference	Hydrologic Impact Significance
SYSTEM YIELDS					
Trial Yield	300	333	33	11	--
Actual Yield	298	330	32	11	Low
TRANSFERS (Actual)					
Northfield-Quabbin	--	--	--	--	--
Millers-Quabbin	--	38	38	--	--
Merrimack-MDC	--	--	--	--	--
Sudbury-MDC	--	--	--	--	--
Framingham-Sudbury	--	--	--	--	--
Quabbin-Wachusett	167	197	30	18	Low
RESERVOIRS					
Quabbin-Net Storage (%)	69	73	--	4	Low
Quabbin-Elevation (Ft-BCB)	519	520	1	1	Low
Quabbin-Area (Sq. Mi.)	34.2	34.7	0.5	1	Low
Wachusett-Net Storage (%)	39	36	--	-3	Low
Wachusett-Elevation (Ft-BCB)	390	390	0	0	--
Wachusett-Area (Sq. Mi.)	6.2	6.2	0	0	--
Sudbury-Net Storage (%)	--	--	--	--	--
Sudbury-Elevation (Ft-BCB)	--	--	--	--	--
Sudbury-Area (Sq. Mi.)	--	--	--	--	--

Table 6.11-18 (Continued)

	Baseline	With Alternative	Difference	Percent Difference	Hydrologic Impact Significance
STREAMFLOW					
Millers River at Erving	403	365	-38	-9	Low
Connecticut River at Montague	8868	8830	-38	0	--
Swift River at Quabbin	55	62	7	13	Low
Chicopee River at Indian Orchard	504	511	7	1	Low
Connecticut River at Thompsonville	10532	10501	-31	0	--
S. Nashua River at Wachusett	4.9	3.9	-1	--	--
Nashua River at E. Pepperell	--	--	--	--	--
Sudbury River at Framingham	--	--	--	--	--
Concord River at Lowell	--	--	--	--	--
Merrimack River at Lowell	--	--	--	--	--
OTHER OR SPECIAL					
Weeks Supply in Quabbin & Wachusett	86	81	-5	-6	--

Notes:

(1) Values in parentheses are not representative of the 600 values used to determine the mean value.
(2) Percentage change in Quabbin Elevation based on reservoir depth of 110 feet.
Percentage change in Wachusett Elevation based on reservoir depth of 95 feet.
Percentage change in Sudbury Elevation based on reservoir depth of 30 feet.
(3) Hyphen (-) indicates datum is not applicable or not meaningful.
(4) See text for reasons for impact significance.

Table 6.11-19: DELTA VALUES QUABBIN RESER. EOM STORAGE - PERCENT OF NET STORAGE

RUN HY-12 06/19/85 MILLERS ALTERNATIVE (WITHOUT TULLY) DM=10, DT=0 IOA= -1 0 0 1 0 2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	-3	-4	-4	-4	-4	-3	-4	-4	-5	-5	-5	-6	-4
2	1931	-6	-7	-7	-7	-8	-7	-5	-5	-4	-5	-5	-5	-6
3	1932	-6	-6	-6	-5	-5	-6	-4	-4	-4	-5	-5	-6	-5
4	1933	-6	-6	-6	-7	-7	-7	-3	-3	-4	-4	-5	-5	-5
5	1934	-5	-6	-6	-7	-7	-6	-3	-2	-3	-3	-3	-4	-5
6	1935	-4	-4	-3	-2	-3	0	0	0	0	-1	-1	-1	-2
7	1936	-2	-2	-2	-3	-3	1	0	0	-1	-1	-2	-2	-1
8	1937	-3	-3	-1	2	0	0	0	0	0	0	-1	-1	0
9	1938	-1	-1	1	1	1	0	0	0	-1	0	0	0	0
10	1939	0	0	0	-1	0	0	0	0	-2	-1	-2	-3	-1
11	1940	-3	-4	-4	-4	-5	-5	1	1	0	0	0	-1	-2
12	1941	-1	-1	-1	-1	-1	-2	-2	-2	-3	-3	-4	-4	-2
13	1942	-5	-5	-5	-6	-6	-2	-2	-3	-3	-3	-4	-4	-4
14	1943	-4	-5	-4	-5	-4	-2	-1	4	2	2	1	1	-1
15	1944	1	0	0	0	-1	0	1	1	2	1	1	1	1
16	1945	0	0	-1	0	-1	4	4	9	9	9	8	8	4
17	1946	7	7	8	8	8	12	11	13	13	13	13	13	10
18	1947	12	12	12	11	12	14	15	11	10	11	10	10	12
19	1948	10	9	9	9	8	11	12	14	9	10	10	10	10
20	1949	10	10	10	11	11	13	12	12	11	11	11	10	11
21	1950	10	9	9	9	9	9	10	10	9	9	9	8	9
22	1951	8	8	10	10	11	14	15	14	13	13	13	12	12
23	1952	12	14	15	16	16	13	6	5	4	5	5	4	10
24	1953	4	4	4	5	7	4	0	0	-1	-1	-2	-2	2
25	1954	-3	-3	-1	-2	-1	1	1	0	0	-1	-1	1	-1
26	1955	1	2	0	0	-1	0	0	1	0	-1	-1	-1	0
27	1956	0	0	-1	0	0	0	0	0	0	-1	-1	-2	0
28	1957	-2	-2	-3	-3	-3	-1	-2	-2	-3	-3	-3	-4	-2
29	1958	-4	-5	-3	-2	-2	-2	2	0	-1	-1	-2	-2	-2
30	1959	-3	-3	-3	-3	-4	-3	0	-1	-1	-2	-2	-2	-2
31	1960	-2	-1	0	0	0	-1	0	0	-1	-1	-2	-1	-1
32	1961	-1	-1	-2	-2	-2	0	0	0	-1	-2	-2	-3	-1
33	1962	-3	-4	-4	-4	-5	-5	-2	-1	-2	-3	-3	-3	-3
34	1963	-3	-4	-3	-4	-4	-3	-1	-2	-2	-3	-3	-3	-3
35	1964	-4	-4	-4	-4	-4	-1	0	-1	-2	-2	-2	-3	-3
36	1965	-3	-4	-4	-4	-5	-5	-5	-6	-6	-6	-7	-7	-5
37	1966	-8	-8	-8	-9	-9	-8	-8	-8	-8	-8	-3	-1	-7
38	1967	0	0	0	0	0	0	3	7	7	6	6	5	3
39	1968	5	4	5	5	4	7	7	7	9	9	8	8	6
40	1969	7	7	8	8	7	8	12	12	12	11	12	12	10
41	1970	11	12	13	13	16	16	18	19	18	18	17	17	16
42	1971	17	16	16	15	15	15	17	19	18	18	17	16	17
43	1972	13	11	12	12	11	14	17	21	22	21	20	20	16
44	1973	20	20	22	24	26	30	31	34	32	33	33	33	28
45	1974	33	32	35	37	34	30	26	24	22	23	23	22	28
46	1975	22	22	22	21	22	23	17	15	16	16	16	17	19
47	1976	18	13	10	4	0	0	0	0	0	-2	-1	-2	3
48	1977	-2	-2	-3	-3	-3	1	3	2	2	2	1	1	0
49	1978	2	2	5	0	0	0	0	0	-1	-2	-3	-4	0
50	1979	-4	-4	-5	-3	-4	0	0	0	-2	-1	-1	-3	-2
	AVER	3	2	3	3	2	3	4	4	4	3	3	3	3

Table 6.11-20: DELTA VALUES QUABBIN RESER. END-OF-MONTH ELEV (BOSTON CITY BASE)

RUN HY-12 06/19/85 MILLERS ALTERNATIVE (WITHOUT TULLY) DM=10, DT=0 IOA= -1 0 0 1 0 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	12	12	12	13	12	11	11	12	11	11	12	12	10
2	98.0	8	8	9	10	10	10	9	9	9	9	9	8	10
3	96.0	8	8	8	8	8	8	8	9	8	9	8	8	8
4	94.0	8	8	8	7	7	7	7	8	8	8	8	8	7
5	92.0	7	6	7	6	7	7	7	8	8	7	8	8	7
6	90.0	6	5	6	6	6	6	6	5	5	6	6	6	7
7	88.0	5	5	5	6	5	5	5	5	5	5	5	6	5
8	86.0	4	4	4	4	4	5	5	5	5	5	4	4	4
9	84.0	4	4	4	4	4	4	5	5	4	4	4	4	4
10	82.0	4	4	4	4	4	4	4	4	4	4	4	4	4
11	80.0	3	3	3	4	4	4	4	4	4	4	4	4	4
12	78.0	3	3	3	3	3	4	4	4	3	4	4	4	3
13	76.0	3	3	3	3	3	4	4	3	3	3	3	3	3
14	74.0	3	3	3	3	3	3	3	3	3	3	3	3	3
15	72.0	3	2	3	2	2	3	2	3	3	3	3	3	3
16	70.0	2	2	2	2	2	1	2	3	3	3	3	3	1
17	68.0	1	1	2	1	0	1	1	2	1	2	2	2	1
18	66.0	1	1	1	1	0	0	1	1	1	1	0	0	1
19	64.0	0	1	0	0	0	0	1	1	1	1	0	0	1
20	62.0	0	0	0	0	0	0	0	0	1	0	0	0	0
21	60.0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	58.0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	56.0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	54.0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	52.0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	50.0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	48.0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	46.0	-1	0	0	0	0	0	0	0	0	0	0	-1	0
29	44.0	-1	-1	0	-1	0	0	0	0	0	0	0	-1	0
30	42.0	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	0
31	40.0	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1
32	38.0	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1
33	36.0	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1
34	34.0	-1	-1	-1	-1	-1	0	0	0	0	-1	-1	-1	-1
35	32.0	-1	-1	-1	-1	-1	0	0	0	0	-1	-1	-1	-1
36	30.0	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
37	28.0	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
38	26.0	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
39	24.0	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
40	22.0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
41	20.0	-1	-1	-2	-1	-2	-1	-1	-1	-1	-1	-1	-1	-1
42	18.0	-1	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1	-1	-1
43	16.0	-1	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1	-1
44	14.0	-2	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1	-1
45	12.0	-2	-2	-2	-2	-2	-2	-1	-1	-1	-2	-1	-2	-2
46	10.0	-2	-2	-2	-2	-2	-2	-1	-1	-1	-2	-2	-2	-2
47	8.0	-2	-2	-3	-2	-2	-2	-1	-1	-2	-2	-2	-2	-2
48	6.0	-2	-3	-3	-3	-3	-3	-2	-2	-2	-2	-2	-2	-2
49	4.0	-3	-3	-3	-3	-3	-3	-2	-2	-2	-3	-2	-2	-2
50	2.0	-4	-4	-4	-4	-5	-4	-4	-4	-4	-4	-3	-3	-4
	AVER	1	1	1	1	1	1	1	2	1	1	1	1	1

However, the median value (50 percent of time) does not change (see Figure 6.11-1).

(3) Table 6.11-21 Actual Transfers--Millers to Quabbin (sorted). The 50-year mean value is 38 MGD, but most of the transfer occurs in March with a maximum monthly value of 467 MGD.

(4) Table 6.11-22 Streamflow--Millers River at Athol, MGD (with alternative, chronological). These are the flows after transfers have been made to Quabbin (see Figure 6.11-2).

(5) Table 6.11-23 Streamflow--Millers River at Erving, MGD (with alternative, chronological).

(6) Table 6.11-24 Streamflow--Millers River at Erving, Percent Reduction (sorted). Note, the right column is a sort of the average annual percentage reductions, not an average of the percentile rows.

(7) Table 6.11-25 Streamflow--Connecticut River at Montague (percent reduction with alternative, chronological).

(8) Table 6.11-26 Outflow from Quabbin Reservoir, MGD (with alternative, differences, sorted). The 50-year mean value is 7 MGD, but as can be seen in the table, there are only a few years having substantially increased discharge, and they are nearly offset by a few years of reduced discharges. For most of the time, there is no difference (zero values) because Quabbin is discharging at its "legally" required rate. Non-zero values are all attributable to changes in spillway discharge quantities when the reservoir is full.

(9) Table 6.11-27 Streamflow, Chicopee River at Indian Orchard, MGD (differences, chronological).

(10) Table 6.11-28 Streamflow, Connecticut River at Thompsonville (percent differences, sorted). Note that the maximum monthly difference is plus 4 percent. This occurred in January 1976, when the flow increased from 11,369 to 11,802 MGD. No transfers were made from Athol to Quabbin on that month, but at the beginning of the month, Quabbin was 100 percent full with the alternative versus 90 percent without. As a result, its spillage increased from 386 to 454 MGD. Furthermore, less water was transferred from Shaft 8 to Quabbin. As a result, the flows in the Chicopee River at Indian Orchard increased by 443 MGD. This quantity represents 4 percent increase at

Table 6.11-21: ACTUAL TRANSFER - MILLERS TO QUABBIN, MGD

RUN HY-12 06/19/85 MILLERS ALTERNATIVE (WITHOUT TULLY) DM=10, DT=0 C= 2 6 6 0 0-2 NTS= 2 NTTS= 2 TYIELD= 333. MGD

N	PCTILE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	221	203	220	271	240	378	467	407	171	108	79	196	126
2	98.0	91	133	204	234	169	359	360	376	159	33	63	102	84
3	96.0	74	118	198	184	147	345	309	354	130	30	24	70	81
4	94.0	47	115	195	167	107	340	282	338	123	4	11	18	72
5	92.0	21	87	188	146	95	335	243	237	102	2	5	10	67
6	90.0	14	81	179	139	87	320	242	236	87	2	1	0	66
7	88.0	3	55	153	137	74	259	223	201	81	2	0	0	62
8	86.0	2	50	126	118	60	237	220	170	64	1	0	0	60
9	84.0	2	38	110	116	57	233	217	125	49	0	0	0	56
10	82.0	0	26	109	108	44	230	204	123	44	0	0	0	54
11	80.0	0	23	98	102	41	223	192	111	43	0	0	0	53
12	78.0	0	20	82	101	38	219	172	95	40	0	0	0	52
13	76.0	0	20	74	86	20	210	171	88	31	0	0	0	51
14	74.0	0	13	66	52	20	194	168	74	26	0	0	0	51
15	72.0	0	11	62	43	6	193	161	66	26	0	0	0	49
16	70.0	0	11	59	39	0	156	133	60	18	0	0	0	46
17	68.0	0	8	53	39	0	149	129	49	17	0	0	0	44
18	66.0	0	7	46	38	0	115	117	49	15	0	0	0	44
19	64.0	0	6	41	24	0	108	90	45	12	0	0	0	42
20	62.0	0	6	23	15	0	107	70	38	12	0	0	0	38
21	60.0	0	5	19	14	0	103	68	32	7	0	0	0	37
22	58.0	0	5	18	13	0	102	59	30	0	0	0	0	36
23	56.0	0	3	16	4	0	92	58	28	0	0	0	0	36
24	54.0	0	1	16	0	0	83	58	27	0	0	0	0	34
25	52.0	0	1	9	0	0	73	57	22	0	0	0	0	34
26	50.0	0	1	9	0	0	73	16	19	0	0	0	0	34
27	48.0	0	0	6	0	0	68	9	15	0	0	0	0	33
28	46.0	0	0	5	0	0	58	7	9	0	0	0	0	31
29	44.0	0	0	2	0	0	57	5	3	0	0	0	0	31
30	42.0	0	0	0	0	0	41	0	3	0	0	0	0	31
31	40.0	0	0	0	0	0	27	0	2	0	0	0	0	31
32	38.0	0	0	0	0	0	13	0	0	0	0	0	0	30
33	36.0	0	0	0	0	0	10	0	0	0	0	0	0	28
34	34.0	0	0	0	0	0	5	0	0	0	0	0	0	28
35	32.0	0	0	0	0	0	0	0	0	0	0	0	0	26
36	30.0	0	0	0	0	0	0	0	0	0	0	0	0	25
37	28.0	0	0	0	0	0	0	0	0	0	0	0	0	25
38	26.0	0	0	0	0	0	0	0	0	0	0	0	0	25
39	24.0	0	0	0	0	0	0	0	0	0	0	0	0	24
40	22.0	0	0	0	0	0	0	0	0	0	0	0	0	23
41	20.0	0	0	0	0	0	0	0	0	0	0	0	0	22
42	18.0	0	0	0	0	0	0	0	0	0	0	0	0	19
43	16.0	0	0	0	0	0	0	0	0	0	0	0	0	17
44	14.0	0	0	0	0	0	0	0	0	0	0	0	0	16
45	12.0	0	0	0	0	0	0	0	0	0	0	0	0	12
46	10.0	0	0	0	0	0	0	0	0	0	0	0	0	10
47	8.0	0	0	0	0	0	0	0	0	0	0	0	0	9
48	6.0	0	0	0	0	0	0	0	0	0	0	0	0	2
49	4.0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	2.0	0	0	0	0	0	0	0	0	0	0	0	0	0
	AVER	9	21	48	44	24	110	90	69	25	4	4	8	38

Table 6.11-22: STREAMFLOW - MILLERS R. AT ATHOL, MGD

RUN HY-12 06/19/85 MILLERS ALTERNATIVE (WITHOUT TULLY) DM=10, DT=0 C= 2 8 8 1 0 2 NTS= 2 NTTS= 2 TYIELD= 333. MGD

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	31	50	50	97	91	165	218	127	92	94	36	31	90
2	1931	30	64	49	49	46	127	416	177	175	63	60	46	108
3	1932	59	59	129	166	235	203	459	141	61	48	35	49	136
4	1933	142	236	151	219	234	338	663	137	80	39	61	216	209
5	1934	203	156	139	193	96	440	543	174	178	59	53	116	196
6	1935	161	197	177	238	221	239	379	140	207	131	44	66	182
7	1936	47	83	93	247	108	1030	573	150	86	52	55	52	216
8	1937	94	100	154	173	277	237	457	384	219	140	77	110	201
9	1938	106	211	217	277	287	263	323	215	281	385	280	1045	323
10	1939	245	180	452	184	170	416	689	199	81	35	48	21	227
11	1940	28	99	110	51	54	134	811	366	270	97	41	42	175
12	1941	36	138	161	141	200	160	289	149	70	42	24	39	120
13	1942	31	76	85	113	82	341	347	135	130	139	76	59	135
14	1943	81	225	182	212	136	195	406	172	135	52	88	48	161
15	1944	83	262	138	48	73	222	500	139	303	135	46	137	173
16	1945	91	92	162	179	136	353	388	213	202	225	130	108	190
17	1946	108	132	140	197	239	271	248	176	170	93	111	70	162
18	1947	137	69	70	140	221	184	464	291	144	71	47	41	156
19	1948	24	140	96	73	165	338	437	216	389	152	38	23	174
20	1949	31	118	87	232	277	249	328	178	59	39	25	35	137
21	1950	33	48	88	210	199	210	423	147	134	42	33	44	133
22	1951	38	133	136	232	426	245	436	160	128	166	154	100	194
23	1952	195	271	261	320	313	359	598	270	103	52	90	66	241
24	1953	67	65	130	169	294	534	857	504	126	45	24	22	236
25	1954	55	141	226	134	124	213	343	460	134	94	79	190	183
26	1955	127	255	385	149	174	362	430	129	152	56	189	99	209
27	1956	551	593	123	444	157	227	828	561	141	51	23	92	316
28	1957	80	105	210	235	154	191	317	191	78	34	18	38	137
29	1958	31	72	110	226	225	256	519	431	74	62	45	80	177
30	1959	113	118	134	168	115	246	458	203	92	83	31	72	153
31	1960	206	247	473	270	208	173	1097	342	266	135	153	245	317
32	1961	255	238	144	91	118	237	730	318	171	89	68	116	214
33	1962	126	154	116	193	115	183	531	190	101	39	62	37	154
34	1963	201	230	147	110	94	190	416	143	69	32	20	34	140
35	1964	59	177	155	127	165	197	457	114	35	24	20	14	128
36	1965	45	32	49	53	73	105	263	103	51	20	18	19	69
37	1966	83	63	74	58	133	169	252	163	52	23	16	40	93
38	1967	90	164	100	103	94	121	513	210	229	188	66	52	161
39	1968	82	111	186	132	177	321	300	168	254	111	31	26	158
40	1969	61	131	182	124	111	140	554	185	160	62	160	142	167
41	1970	90	236	177	112	237	236	511	211	216	56	44	60	181
42	1971	112	110	111	79	121	243	501	159	95	65	70	66	144
43	1972	73	110	263	266	183	279	559	188	262	131	56	65	203
44	1973	85	193	233	186	236	260	425	173	198	182	101	72	195
45	1974	78	116	364	241	322	404	409	302	119	67	30	140	215
46	1975	157	178	244	245	172	341	520	156	159	126	132	155	215
47	1976	360	482	328	414	715	526	407	314	80	100	108	57	322
48	1977	107	93	96	56	68	415	447	239	114	67	54	78	153
49	1978	236	245	242	472	276	285	613	204	147	37	47	28	235
50	1979	70	37	80	410	193	935	534	367	152	83	111	179	264
	AVER	113	157	168	185	187	290	484	224	149	88	69	96	184

Table 6.11-23: STREAMFLOW - MILLERS R. AT ERVING, MGD

RUN HY-12 06/19/85 MILLERS ALTERNATIVE (WITHOUT TULLY) DM=10, DT=0 C= 2 8 9 1 0 2 NTS= 2 NTTS= 2 TYIELD= 333. MGD

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	58	94	94	193	223	373	408	241	173	177	67	58	180
2	1931	57	120	93	93	85	298	920	429	404	119	112	86	234
3	1932	111	110	263	432	440	380	1008	292	115	91	66	92	282
4	1933	267	491	283	412	439	634	1558	284	151	72	115	420	424
5	1934	380	292	261	363	180	926	1231	433	345	111	100	226	405
6	1935	302	375	426	566	414	651	718	305	411	249	82	123	385
7	1936	88	160	189	463	203	2234	1074	281	162	97	102	98	432
8	1937	177	188	453	561	519	443	857	720	467	263	144	207	416
9	1938	200	473	493	620	544	492	605	403	527	723	524	1959	628
10	1939	459	337	848	346	319	780	1292	373	151	65	124	53	429
11	1940	48	193	225	98	104	267	1849	725	460	187	74	72	358
12	1941	66	245	309	264	338	263	527	254	121	116	58	79	219
13	1942	64	151	203	239	152	936	636	264	275	261	119	91	284
14	1943	142	409	402	387	292	598	757	641	273	97	145	87	353
15	1944	159	524	229	82	126	508	991	320	503	239	86	209	330
16	1945	146	167	300	339	245	833	771	714	499	499	229	176	411
17	1946	168	272	333	387	367	706	468	484	412	192	204	116	342
18	1947	217	111	119	250	495	524	899	606	323	138	95	91	321
19	1948	55	298	192	126	254	859	787	602	732	273	75	50	358
20	1949	56	188	154	444	501	554	612	354	100	58	38	52	258
21	1950	54	74	174	422	356	485	907	353	307	82	58	85	278
22	1951	69	309	439	471	854	670	1020	336	256	283	264	173	425
23	1952	377	667	530	686	599	645	1122	535	332	125	158	119	490
24	1953	100	105	259	408	649	1092	1499	906	271	104	61	47	457
25	1954	101	227	515	270	344	523	668	805	269	148	119	328	360
26	1955	217	500	639	266	323	687	858	332	323	126	428	176	406
27	1956	831	1027	247	596	261	405	1594	900	262	87	42	124	531
28	1957	177	185	638	793	499	336	617	383	168	73	36	53	329
29	1958	49	126	386	467	392	504	1111	743	150	113	88	107	353
30	1959	146	182	220	332	195	539	968	376	156	145	57	110	286
31	1960	401	558	812	464	419	328	1976	589	456	224	237	420	572
32	1961	395	418	254	163	257	620	1205	560	278	143	87	136	376
33	1962	155	201	157	304	186	394	1047	379	169	67	79	50	265
34	1963	271	336	233	169	145	421	928	311	128	56	38	46	257
35	1964	76	219	226	279	319	575	821	239	60	48	34	28	243
36	1965	59	52	82	74	143	235	478	184	84	40	37	39	125
37	1966	113	101	147	123	253	469	416	292	93	40	36	64	178
38	1967	133	270	167	200	194	239	1162	626	464	320	109	99	331
39	1968	131	177	381	221	309	750	566	320	589	228	64	53	316
40	1969	85	220	408	222	206	369	1147	422	290	142	371	221	342
41	1970	141	509	434	243	644	496	1132	566	417	105	83	91	402
42	1971	151	189	198	147	222	436	1007	422	162	110	134	127	275
43	1972	155	223	496	501	324	725	1207	569	557	286	124	100	439
44	1973	135	393	530	566	567	801	916	528	393	352	173	107	454
45	1974	118	186	867	565	614	776	730	577	234	125	51	224	422
46	1975	251	335	428	446	372	754	969	289	331	294	284	432	432
47	1976	827	831	614	708	1194	921	735	581	157	139	183	91	578
48	1977	193	148	184	98	119	1023	892	453	210	111	96	147	307
49	1978	536	495	579	933	486	547	1085	357	256	75	92	47	457
50	1979	97	72	177	817	370	1784	991	720	277	129	169	285	493
	AVER	195	291	346	372	361	636	955	468	294	167	127	169	364

Table 6.11-24: DELTA VALUES STREAMFLOW - MILLERS R. AT ERVING, PCT

RUN HY-12 06/19/85 MILLERS ALTERNATIVE (WITHOUT TULLY) DM=10, DT=0 IOA= -1 0 0 3 0 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	98.0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	96.0	0	0	0	0	0	0	0	0	0	0	0	0	-1
4	94.0	0	0	0	0	0	0	0	0	0	0	0	0	-1
5	92.0	0	0	0	0	0	0	0	0	0	0	0	0	-2
6	90.0	0	0	0	0	0	0	0	0	0	0	0	0	-3
7	88.0	0	0	0	0	0	0	0	0	0	0	0	0	-3
8	86.0	0	0	0	0	0	0	0	0	0	0	0	0	-3
9	84.0	0	0	0	0	0	0	0	0	0	0	0	0	-3
10	82.0	0	0	0	0	0	0	0	0	0	0	0	0	-3
11	80.0	0	0	0	0	0	0	0	0	0	0	0	0	-4
12	78.0	0	0	0	0	0	0	0	0	0	0	0	0	-4
13	76.0	0	0	0	0	0	0	0	0	0	0	0	0	-4
14	74.0	0	0	0	0	0	0	0	0	0	0	0	0	-4
15	72.0	0	0	0	0	0	0	0	0	0	0	0	0	-4
16	70.0	0	0	0	0	0	0	0	0	0	0	0	0	-4
17	68.0	0	0	0	0	0	-2	0	0	0	0	0	0	-4
18	66.0	0	0	0	0	0	-3	0	0	0	0	0	0	-4
19	64.0	0	0	0	0	0	-4	0	0	0	0	0	0	-4
20	62.0	0	0	0	0	0	-5	0	-1	0	0	0	0	-4
21	60.0	0	0	0	0	0	-9	0	-1	0	0	0	0	-4
22	58.0	0	0	0	0	0	-10	-1	-1	0	0	0	0	-5
23	56.0	0	0	-1	0	0	-11	-1	-3	0	0	0	0	-5
24	54.0	0	0	-3	0	0	-11	-1	-4	0	0	0	0	-5
25	52.0	0	0	-3	0	0	-11	-2	-6	0	0	0	0	-5
26	50.0	0	0	-4	0	0	-12	-6	-6	0	0	0	0	-5
27	48.0	0	-1	-8	0	0	-13	-7	-7	0	0	0	0	-5
28	46.0	0	-1	-8	-2	0	-16	-7	-8	0	0	0	0	-5
29	44.0	0	-2	-9	-3	0	-16	-7	-9	0	0	0	0	-5
30	42.0	0	-2	-10	-5	0	-16	-8	-9	-2	0	0	0	-5
31	40.0	0	-2	-11	-5	0	-17	-8	-10	-3	0	0	0	-6
32	38.0	0	-2	-12	-6	0	-19	-11	-10	-4	0	0	0	-6
33	36.0	0	-3	-13	-8	0	-21	-11	-12	-5	0	0	0	-6
34	34.0	0	-3	-13	-9	0	-22	-11	-13	-6	0	0	0	-6
35	32.0	0	-4	-15	-10	0	-22	-14	-13	-6	0	0	0	-6
36	30.0	0	-4	-15	-12	-1	-22	-14	-14	-7	0	0	0	-6
37	28.0	0	-5	-16	-12	-4	-23	-15	-16	-8	0	0	0	-6
38	26.0	0	-6	-16	-13	-6	-23	-15	-18	-9	0	0	0	-7
39	24.0	0	-6	-17	-16	-6	-24	-16	-18	-9	0	0	0	-7
40	22.0	0	-6	-20	-18	-8	-24	-16	-20	-11	0	0	0	-8
41	20.0	0	-7	-20	-18	-11	-24	-16	-21	-12	0	0	0	-8
42	18.0	-1	-8	-20	-18	-12	-25	-16	-22	-12	0	0	0	-8
43	16.0	-1	-10	-22	-19	-15	-26	-16	-26	-13	0	0	0	-9
44	14.0	-2	-11	-23	-22	-17	-27	-17	-28	-17	-1	0	0	-9
45	12.0	-5	-16	-24	-24	-18	-28	-18	-31	-18	-1	-1	-1	-9
46	10.0	-6	-17	-25	-25	-18	-29	-19	-32	-20	-1	-3	-4	-9
47	8.0	-14	-19	-26	-27	-21	-31	-19	-33	-21	-2	-4	-4	-10
48	6.0	-15	-21	-29	-27	-22	-31	-20	-37	-22	-6	-5	-14	-10
49	4.0	-16	-21	-32	-29	-23	-31	-20	-38	-22	-13	-18	-19	-10
50	2.0	-21	-23	-34	-33	-27	-32	-22	-39	-23	-24	-26	-37	-17
	AVER	-2	-4	-9	-7	-4	-13	-7	-10	-5	-1	-1	-2	-5

Table 6.11-25: DELTA VALUES STREAMFLOW - CONN. R. AT MONTAGUE, PCT

RUN HY-12 06/19/85 MILLERS ALTERNATIVE (WITHOUT TULLY) DM=10, DT=0 IOA= -1 0 0 3 0 2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0	0	0	0	-1	-1	0	0	0	0	0	0	0
2	1931	0	0	0	0	0	-1	-1	-1	-1	0	0	0	0
3	1932	0	0	0	-1	0	0	-1	0	0	0	0	0	0
4	1933	0	0	0	0	0	0	-1	0	0	0	0	0	0
5	1934	0	0	0	0	0	-1	-1	-1	0	0	0	0	0
6	1935	0	0	-1	-1	0	-2	0	0	0	0	0	0	0
7	1936	0	0	0	0	0	-1	0	0	0	0	0	0	0
8	1937	0	0	-2	-2	0	0	0	0	-1	0	0	0	0
9	1938	0	-1	-1	-1	0	0	0	0	0	0	0	0	0
10	1939	0	0	0	0	0	0	0	0	0	0	0	0	0
11	1940	0	0	0	0	0	0	-1	0	0	0	0	0	0
12	1941	0	0	-1	-1	0	0	0	0	0	0	0	0	0
13	1942	0	0	0	0	0	-2	0	0	0	0	0	0	0
14	1943	0	0	-1	0	-1	-2	0	-2	0	0	0	0	0
15	1944	0	0	0	0	0	-1	0	0	-1	0	0	0	0
16	1945	0	0	0	-1	0	-2	0	-2	-1	0	0	0	0
17	1946	0	0	-1	-1	0	-1	0	-1	-1	0	0	0	0
18	1947	0	0	0	0	-1	-2	0	0	0	0	0	0	0
19	1948	0	0	0	0	0	-1	-1	-1	0	0	0	0	0
20	1949	0	0	0	-1	-1	-1	0	0	0	0	0	0	0
21	1950	0	0	0	0	0	-1	0	0	0	0	0	0	0
22	1951	0	-1	-2	0	-1	-2	0	0	0	0	0	0	0
23	1952	0	-1	-1	-1	0	0	0	0	-1	0	0	0	0
24	1953	0	0	-1	-2	-1	0	0	0	0	0	0	0	0
25	1954	0	0	-2	0	-1	-1	0	0	0	0	0	-2	0
26	1955	0	-1	0	0	0	0	0	-1	0	0	0	0	0
27	1956	0	0	0	0	0	0	0	0	0	0	0	0	0
28	1957	0	0	0	-1	0	-1	0	0	0	0	0	0	0
29	1958	0	0	-1	-1	0	0	-1	0	0	0	0	0	0
30	1959	0	0	0	-1	0	-1	-1	0	0	0	0	0	0
31	1960	-1	-1	0	0	0	0	0	0	0	0	0	-1	0
32	1961	0	0	0	0	-1	-2	0	0	0	0	0	0	0
33	1962	0	0	0	0	0	-1	-1	-1	0	0	0	0	0
34	1963	-1	0	-1	0	0	-1	-1	0	0	0	0	0	0
35	1964	0	0	0	-2	0	-2	0	0	0	0	0	0	0
36	1965	0	0	0	0	0	0	0	0	0	0	0	0	0
37	1966	0	0	0	0	0	-1	0	0	0	0	0	0	0
38	1967	0	0	0	0	0	0	-1	-2	0	0	0	0	0
39	1968	0	0	-1	0	0	-1	0	0	-1	-1	0	0	0
40	1969	0	0	-1	0	0	-1	-1	0	0	0	-1	0	0
41	1970	0	-1	-1	0	-2	-1	-1	-1	0	0	0	0	-1
42	1971	0	0	0	0	0	0	-1	-1	0	0	0	0	0
43	1972	0	0	0	0	0	-2	-1	-1	-1	0	0	0	0
44	1973	0	0	-2	-2	-1	-2	-1	-1	0	-1	0	0	-1
45	1974	0	0	-1	-2	0	0	0	0	0	0	0	0	0
46	1975	0	0	-1	0	-1	-1	0	0	-1	0	0	-1	0
47	1976	-1	0	0	0	0	0	0	0	0	0	-1	0	0
48	1977	0	0	0	0	0	-1	-1	-1	0	0	0	0	0
49	1978	-1	0	-2	0	0	0	0	0	0	0	0	0	0
50	1979	0	0	0	-1	0	0	0	0	0	0	0	0	0
	AVER	0	0	0	0	0	-1	0	0	0	0	0	0	0

Table 6.11-26: DELTA VALUES OUTFLOW FROM QUABBIN RESERVOIR, MGD

RUN HY-12 06/19/85 MILLERS ALTERNATIVE (WITHOUT TULLY) DM=10, DT=0 IOA= -1 0 0 1 1 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0.0	382.9	324.2	433.7	364.9	368.8	511.0	210.9	167.9	0.0	0.0	0.0	118.5
2	98.0	0.0	0.0	161.3	373.5	224.1	229.3	464.7	119.9	0.0	0.0	0.0	0.0	77.5
3	96.0	0.0	0.0	0.0	0.0	133.5	142.5	363.4	105.8	0.0	0.0	0.0	0.0	66.4
4	94.0	0.0	0.0	0.0	0.0	0.0	82.1	228.2	58.1	0.0	0.0	0.0	0.0	42.0
5	92.0	0.0	0.0	0.0	0.0	0.0	0.0	95.1	24.3	0.0	0.0	0.0	0.0	38.2
6	90.0	0.0	0.0	0.0	0.0	0.0	0.0	41.1	20.3	0.0	0.0	0.0	0.0	30.0
7	88.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0	17.9
8	86.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.8
9	84.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0
10	82.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.8
11	80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7
12	78.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
13	76.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3
14	74.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7
15	72.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	68.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	66.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	64.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	62.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	58.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	56.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	54.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	52.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	48.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	46.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	44.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	42.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	38.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	36.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	34.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	32.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	28.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	26.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	22.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.6
45	12.0	0.0	0.0	0.0	0.0	0.0	-6.1	0.0	0.0	0.0	0.0	0.0	0.0	-4.8
46	10.0	0.0	0.0	0.0	0.0	0.0	-17.3	0.0	0.0	0.0	0.0	0.0	0.0	-6.8
47	8.0	0.0	0.0	0.0	0.0	0.0	-20.5	-5.6	0.0	0.0	0.0	0.0	0.0	-9.9
48	6.0	0.0	0.0	0.0	-3.1	0.0	-34.8	-22.1	-6.7	0.0	0.0	0.0	0.0	-10.3
49	4.0	-32.3	0.0	0.0	-14.7	-14.6	-89.3	-53.8	-32.0	-4.5	0.0	0.0	0.0	-23.2
50	2.0	-51.5	0.0	-49.7	-141.7	-16.5	-312.3	-82.2	-93.6	-16.7	-177.2	-57.0	-31.3	-26.5
	AVER	-1.7	7.7	8.7	13.0	13.8	6.8	30.9	8.1	2.9	-3.5	-1.1	-0.6	7.0

Table 6.11-27: DELTA VALUES STREAMFLOW - CHICOPEE R. AT INDIAN ORCHARD, MGD

RUN HY-12 06/19/85 MILLERS ALTERNATIVE (WITHOUT TULLY) DM=10, DT=0 IOA= -1 0 0 1 1 2

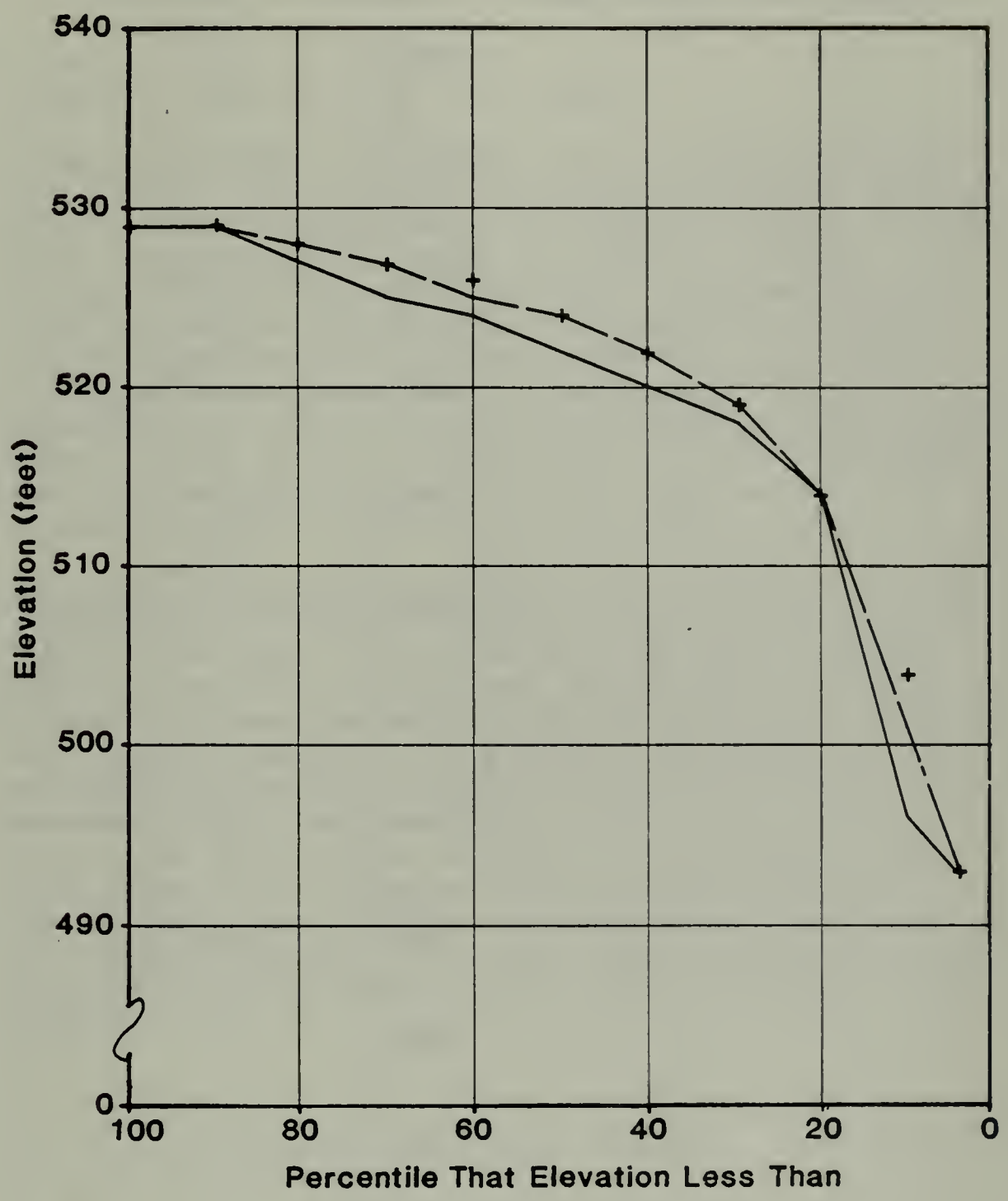
NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1931	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1932	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1933	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	1934	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	1935	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1936	0.0	0.0	0.0	0.0	0.0	0.0	95.1	0.0	0.0	0.0	0.0	0.0	7.8
8	1937	0.0	0.0	0.0	0.0	133.5	0.0	0.0	-93.6	0.0	0.0	0.0	0.0	2.3
9	1938	0.0	0.0	0.0	0.0	0.0	82.1	4.4	0.0	0.0	-177.2	0.0	-31.3	-10.3
10	1939	-32.3	0.0	0.0	-3.1	-14.6	-6.1	0.0	24.3	0.0	0.0	0.0	0.0	-2.6
11	1940	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	1941	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	1942	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	1943	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	1944	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	1945	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	1946	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1947	0.0	0.0	0.0	0.0	0.0	0.0	0.0	210.9	0.0	0.0	0.0	0.0	17.9
19	1948	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	167.9	0.0	0.0	0.0	13.8
20	1949	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	1950	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	1951	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	1952	0.0	0.0	0.0	0.0	0.0	229.3	511.0	58.1	0.0	0.0	0.0	0.0	66.4
24	1953	0.0	0.0	0.0	0.0	0.0	142.5	363.4	0.0	0.0	0.0	0.0	0.0	42.0
25	1954	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.3	0.0	0.0	0.0	0.0	1.7
26	1955	0.0	0.0	161.3	0.0	0.0	-89.3	-5.6	0.0	0.0	0.0	0.0	0.0	5.7
27	1956	-51.5	0.0	0.0	-141.7	-16.5	-17.3	0.0	-32.0	-16.7	0.0	0.0	0.0	-23.2
28	1957	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	1958	0.0	0.0	0.0	0.0	0.0	0.0	0.0	105.8	0.0	0.0	0.0	0.0	9.0
30	1959	0.0	0.0	0.0	0.0	0.0	0.0	-82.2	0.0	0.0	0.0	0.0	0.0	-6.8
31	1960	0.0	0.0	-49.7	-14.7	0.0	0.0	-53.8	0.0	0.0	0.0	0.0	0.0	-9.9
32	1961	0.0	0.0	0.0	0.0	0.0	0.0	41.1	0.0	-4.5	0.0	0.0	0.0	3.0
33	1962	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	1964	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	1965	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	1966	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-57.0	0.0	-4.8
38	1967	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	1969	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	1973	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	1974	0.0	0.0	0.0	0.0	224.1	368.8	228.2	119.9	0.0	0.0	0.0	0.0	77.5
46	1975	0.0	0.0	0.0	0.0	0.0	0.0	464.7	0.0	0.0	0.0	0.0	0.0	38.2
47	1976	0.0	382.9	324.2	433.7	364.9	-34.8	-22.1	-6.7	0.0	0.0	0.0	0.0	118.5
48	1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	1978	0.0	0.0	0.0	373.5	0.0	-20.5	0.0	0.0	0.0	0.0	0.0	0.0	30.0
50	1979	0.0	0.0	0.0	0.0	0.0	-312.3	0.0	0.0	0.0	0.0	0.0	0.0	-26.5
	AVER	-1.7	7.7	8.7	13.0	13.8	6.8	30.9	8.1	2.9	-3.5	-1.1	-0.6	7.0

Table 6.11-28: DELTA VALUES STREAMFLOW - CONN. R. AT THOMPSONVILLE, CT., PCT

RUN HY-12 06/19/85 MILLERS ALTERNATIVE (WITHOUT TULLY) DM=10, DT=0 IOA= -1 0 0 3 0 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0	2	3	4	2	2	2	1	1	0	0	0	1
2	98.0	0	0	1	2	2	2	1	1	0	0	0	0	0
3	96.0	0	0	0	0	1	1	1	1	0	0	0	0	0
4	94.0	0	0	0	0	0	0	1	0	0	0	0	0	0
5	92.0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	90.0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	88.0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	86.0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	84.0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	82.0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	80.0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	78.0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	76.0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	74.0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	72.0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	70.0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	68.0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	66.0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	64.0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	62.0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	60.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
22	58.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
23	56.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
24	54.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
25	52.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
26	50.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
27	48.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
28	46.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
29	44.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
30	42.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
31	40.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
32	38.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
33	36.0	0	0	-1	0	0	-1	0	0	0	0	0	0	0
34	34.0	0	0	-1	0	0	-1	0	0	0	0	0	0	0
35	32.0	0	0	-1	0	0	-1	-1	0	0	0	0	0	0
36	30.0	0	0	-1	-1	0	-1	-1	0	0	0	0	0	0
37	28.0	0	0	-1	-1	0	-1	-1	-1	0	0	0	0	0
38	26.0	0	0	-1	-1	0	-1	-1	-1	0	0	0	0	0
39	24.0	0	0	-1	-1	0	-1	-1	-1	0	0	0	0	0
40	22.0	0	0	-1	-1	0	-1	-1	-1	0	0	0	0	0
41	20.0	0	0	-1	-1	-1	-1	-1	-1	0	0	0	0	0
42	18.0	0	0	-1	-1	-1	-1	-1	-1	0	0	0	0	0
43	16.0	0	0	-1	-1	-1	-1	-1	-1	-1	0	0	0	0
44	14.0	0	0	-1	-1	-1	-1	-1	-1	-1	0	0	0	0
45	12.0	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0
46	10.0	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0
47	8.0	0	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0
48	6.0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	0
49	4.0	-1	-1	-1	-2	-1	-1	-1	-1	-1	-1	-1	-1	0
50	2.0	-1	-1	-2	-2	-1	-2	-1	-2	-1	-2	-2	-1	-1
	AVER	0	0	0	0	0	-1	0	0	0	0	0	0	0

Figure 6.11-1.
Quabbin Reservoir End-of-Month Elevation



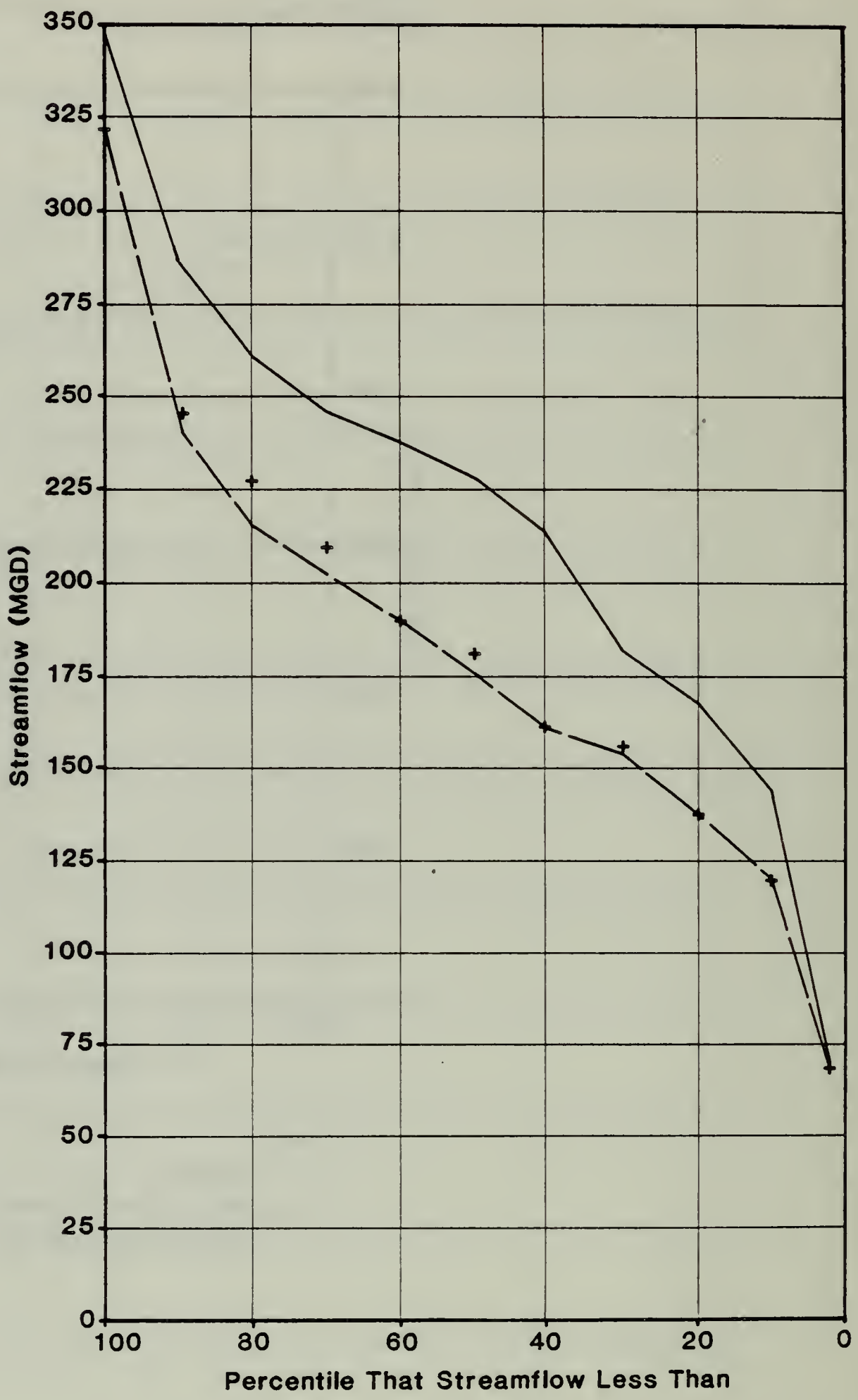
Key:

—— Baseline

— — Alternative without Tully River

\+ Alternative with Tully River

Figure 6.11-2.
Millers River Streamflow at Athol



Key:

—— Baseline

— — Alternative without Tully River

\+ Alternative with Tully River

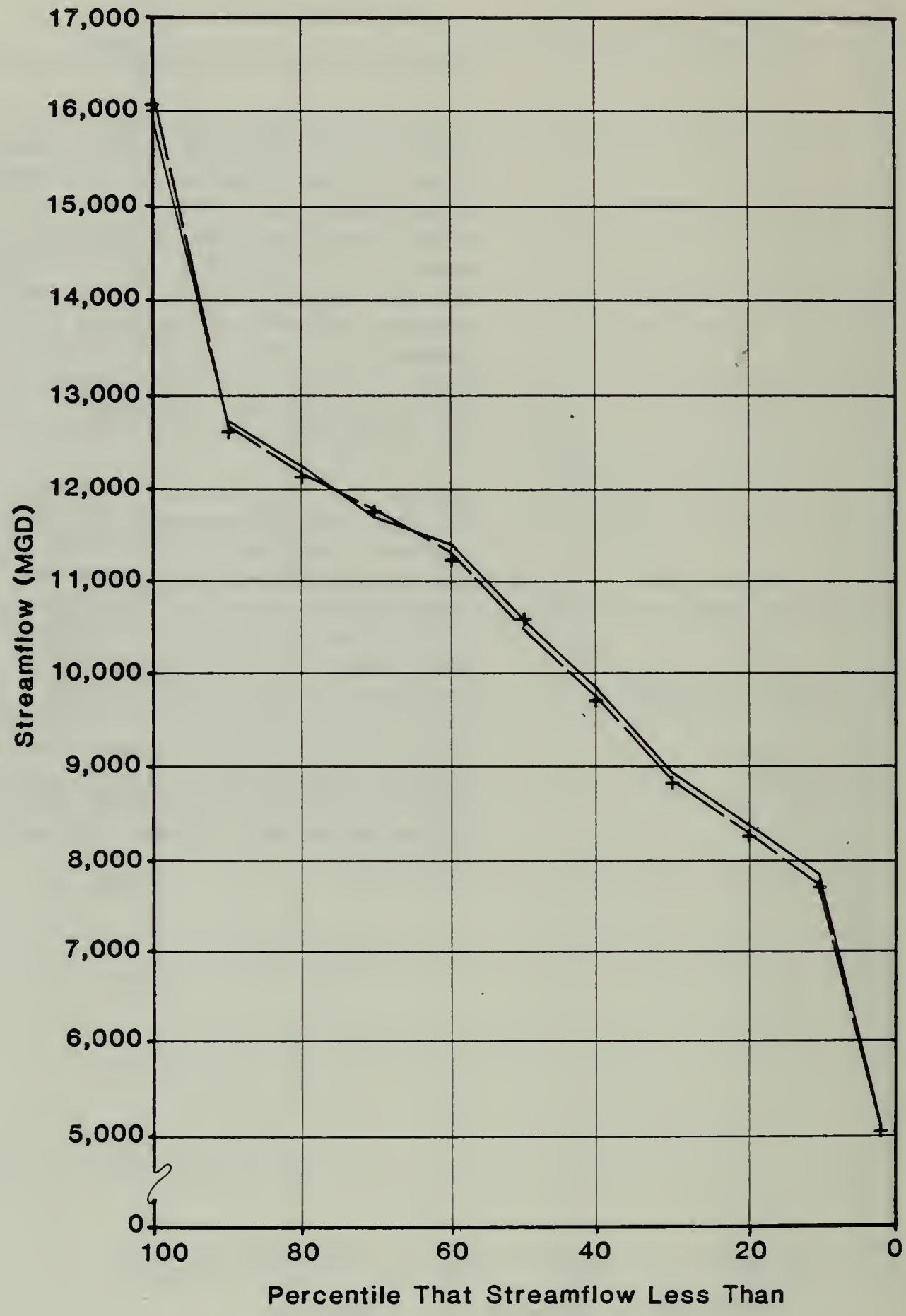
Thompsonville, but it is less significant than might be inferred from examining only the table of percentage differences at Thompsonville (see Figure 6.11-3).

HYDROLOGY IMPACTS (MILLERS WITH TULLY)

A safe yield model run was made for the Millers-With-Tully alternative. The run number, HY-13 dated 06/07/85, applies to an 11-foot diameter tunnel from Athol to Quabbin, and an 8-foot diameter tunnel from Tully Reservoir to Athol. Two trials were made, the first with the alternative inactive using a trial yield of 300 MGD (safe yield for baseline), and the second with the alternative active using a trial yield of 338 MGD (safe yield for Millers-With-Tully). Summary data for the first trial (baseline) are the same as shown in Table 6.11-16. Summary data for the second trial (338 MGD) are shown in Table 6.11-29. The mean values of key parameters are shown in Table 6.11-30.

Except for the increase of 5 MGD in the safe yield (333 to 338 MGD) and an increase of 7 MGD in the transfer from the Millers River Basin to Quabbin (38 to 45 MGD), the mean values of the key parameters are generally only slightly higher than those for the Millers-Without-Tully alternative. The tables of monthly values for the same parameters that were used for the Millers-Without-Tully discussion are included in this section except for Table 308C, the stream-flow of the Millers River at Athol. It is expected that these flows would be similar to those for the Millers-Without-Tully case, with the extra transfers attributable to the transfer from the Tully River. The differences, if any, would be caused by hydraulic rather than hydrologic considerations.

Figure 6.11-3.
Connecticut River Streamflow at Thompsonville



Key:

—— Baseline
—— Alternative without Tully
\+ Alternative with Tully

Table 6.11-29: SUMMARY OUTPUT FOR TRIAL NO. 2

RUN HY-13 06/07/85 MILLERS ALTERNATIVE (WITH TULLY) DM=11, DT=8 NMFAIL = 8 1 2 8 NTTS= 2 TYIELD= 338. MGD

TOTAL TRANSFERS MGD	SHAFT 8 TO QUABBIN	SHAFT 8 TO WACH	QUABBIN TO WACH	WACH TO MARL TUN	NORTHF TO QUABBIN	MILLERS TO QUABBIN	WACH TO SUDBURY	SUDBURY TO BOSTON	MERRIMACK TO BOSTON	PLYMOUTH TO BOSTON	LOCALS TO SYSTEM	FRAM TO SUDBURY
POTENTIAL =	44.06	0.28	398.91	311.46	0.0	69.26	2.00	0.0	0.0	0.0	0.0	0.0
ACTUAL =	41.91	2.43	201.49	308.80	0.0	45.12	2.00	0.0	0.0	0.0	0.0	0.0
PCT =	95.13	861.90	50.51	99.14	0.0	65.14	100.00	0.0	0.0	0.0	0.0	0.0

	QUABBIN	WACHUSETT	SUDBURY	FRAMINGHAM	FRAM#1	FRAM#2	FRAM#3
MEAN RESERVOIR ELEVATION - FT BCB	520.55	390.23	260.00	177.58	0.0	0.0	0.0

WATER BALANCE - MGD

1	WATERSHED INFLOW	163.57	119.14	20.23	53.03
2	PRECIP ON RESERVOIRS	74.88	13.52	4.31	1.77
3	EVAPORATION LOSS	-46.01	-8.12	-2.64	-1.08
4	SEEPAGE LOSS	0.0	-0.92	0.0	0.0
5	OUTFLOW TO STREAM	-64.43	-3.85	-23.90	-77.61
6	CONDUIT TRANSFER IN	87.03	203.92	2.00	23.90
7	CONDUIT TRANSFER OUT	-201.49	-310.80	0.0	0.0
8	DIRECT WITHDRAWAL	-13.56	-12.90	0.0	0.0
11	RESERVOIR YIELD-MGD	192.45	123.62	21.90	53.72
	RESERVOIR YIELD-MGD/SM	1.04	1.15	1.00	1.01

INTERBASIN TRANSFERS - MGD

CONNECTICUT TO NASHUA	203.92
NASHUA TO SUDBURY RESERVOIR	2.00
NASHUA TO SUDBURY & BOSTON	92.67
WEST TO SUDBURY & BOSTON	296.59
SUDBURY TO BOSTON	0.0

SYSTEM ACTUAL YIELD - MGD

FRAM./BOSTON	296.59
WEST	38.66
TOTAL	335.25

Table 6.11-30: Summary of Hydrologic Impacts Millers With Tully, Alternative, Run No. HY-13

(Units in MGD except as noted)
(Values are mean for 50 years)

	Baseline	With Alternative	Difference	Percent Difference	Hydrologic Impact Significance
SYSTEM YIELDS					
Trial Yield	300	338	38	13	--
Actual Yield	298	335	37	12	Low
TRANSFERS (Actual)					
Northfield-Quabbin	--	--	--	--	--
Millers-Quabbin	--	45	45	--	--
Merrimack-MDC	--	--	--	--	--
Sudbury-MDC	--	--	--	--	--
Framingham-Sudbury	--	--	--	--	--
Quabbin-Wachusett	167	201	34	20	Low
RESERVOIRS					
Quabbin-Net Storage (%)	69	74	--	5	Low
Quabbin-Elevation (Ft-BCB)	519	521	2	2	Low
Quabbin-Area (Sq. Mi.)	34.2	34.8	0.6	2	Low
Wachusett-Net Storage (%)	39	36	--	-3	Low
Wachusett-Elevation (Ft-BCB)	390	390	0	0	Low
Wachusett-Area (Sq. Mi.)	6.2	6.2	0	0	--
Sudbury-Net Storage (%)	--	--	--	--	--
Sudbury-Elevation (Ft-BCB)	--	--	--	--	--
Sudbury-Area (Sq. Mi.)	--	--	--	--	--

Table 6.11-30 (Continued)

	Baseline	With Alternative	Difference	Percent Difference	Hydrologic Impact Significance
STREAMFLOW					
Millers River at Erving	403	358	-45	-11	Low
Connecticut River at Montague	8868	8823	-45	-1	Low
Swift River at Quabbin	55	64	9	16	Low
Chicopee River at Indian Orchard	504	513	9	2	Low
Connecticut River at Thompsonville	10532	10496	-36	0	Low
S. Nashua River at Wachusett	4.9	3.9	-1	--	Low
Nashua River at E. Pepperell	--	--	--	--	--
Sudbury River at Framingham	--	--	--	--	--
Concord River at Lowell	--	--	--	--	--
Merrimack River at Lowell	--	--	--	--	--
OTHER OR SPECIAL					
Weeks Supply in Quabbin & Wachusett					

Notes:

(1) Values in parentheses are not representative of the 600 values used to determine the mean value.
(2) Percentage change in Quabbin Elevation based on reservoir depth of 110 feet.
Percentage change in Wachusett Elevation based on reservoir depth of 95 feet.
Percentage change in Sudbury Elevation based on reservoir depth of 30 feet.
(3) Hyphen (-) indicates datum is not applicable or not meaningful.
(4) See text for reasons for impact significance.

Table 6.11-31: DELTA VALUES QUABBIN RESER. EOM STORAGE - PERCENT OF NET STORAGE

RUN HY-13 06/07/85 MILLERS ALTERNATIVE (WITH TULLY) DM=11, DT=8 IOA= -1 0 0 1 0 2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	-4	-4	-5	-5	-4	-3	-4	-4	-5	-5	-6	-6	-5
2	1931	-7	-7	-7	-8	-8	-8	-5	-4	-4	-4	-5	-5	-6
3	1932	-5	-6	-6	-4	-5	-5	-3	-3	-4	-4	-5	-5	-5
4	1933	-6	-5	-6	-6	-6	-7	-1	-1	-2	-3	-3	-3	-4
5	1934	-4	-4	-5	-5	-6	-4	0	1	0	0	-1	-1	-2
6	1935	-2	-2	-1	1	1	4	4	4	3	3	3	2	2
7	1936	2	1	1	1	0	3	0	0	-1	-1	-2	-3	0
8	1937	-3	-4	-1	2	0	0	0	0	0	0	-1	-1	-1
9	1938	-1	-1	1	2	1	0	0	0	-1	0	0	0	0
10	1939	0	0	0	-1	0	0	0	0	-2	-1	-3	-3	-1
11	1940	-4	-4	-4	-5	-5	-6	2	1	0	0	-1	-1	-2
12	1941	-2	-2	-2	-1	-2	-2	-2	-3	-3	-4	-4	-5	-3
13	1942	-5	-6	-6	-6	-7	-1	-2	-3	-2	-3	-4	-4	-4
14	1943	-4	-5	-4	-4	-4	-1	0	6	4	4	3	3	0
15	1944	2	2	2	2	1	2	4	4	5	4	4	3	3
16	1945	3	3	2	2	2	8	9	14	14	14	14	13	8
17	1946	13	12	13	14	13	18	17	17	15	14	15	15	15
18	1947	14	14	14	13	14	17	15	11	10	11	10	10	13
19	1948	9	9	9	8	8	11	13	14	9	10	9	10	10
20	1949	10	10	9	12	11	13	12	13	11	11	11	10	11
21	1950	10	9	9	9	9	10	11	10	10	9	9	8	9
22	1951	8	9	11	11	13	16	18	16	16	15	15	14	13
23	1952	14	17	18	19	16	13	6	5	5	5	5	5	11
24	1953	4	4	4	5	7	4	0	0	-1	-1	-2	-3	2
25	1954	-3	-4	-2	-2	-1	1	2	0	0	-1	-1	1	-1
26	1955	1	2	0	0	-1	0	0	1	0	-1	-1	-1	0
27	1956	0	0	-2	0	0	0	0	0	0	-1	-1	-2	0
28	1957	-2	-3	-3	-3	-3	-2	-2	-2	-3	-3	-4	-4	-3
29	1958	-5	-5	-3	-2	-2	-2	3	0	-1	-2	-2	-3	-2
30	1959	-3	-4	-4	-4	-4	-3	0	-1	-1	-2	-2	-3	-3
31	1960	-2	0	0	0	0	-1	0	0	-1	-1	-2	-1	-1
32	1961	-2	-2	-2	-3	-2	1	0	0	-2	-2	-3	-3	-2
33	1962	-4	-4	-5	-5	-5	-5	-2	-1	-2	-3	-3	-4	-3
34	1963	-3	-4	-3	-4	-4	-3	-1	-1	-2	-2	-3	-3	-3
35	1964	-4	-4	-4	-3	-4	0	0	0	-1	-1	-2	-2	-2
36	1965	-3	-3	-3	-4	-4	-5	-5	-5	-6	-6	-7	-7	-5
37	1966	-8	-8	-9	-9	-10	-8	-8	-8	-9	-8	-3	-1	-7
38	1967	0	0	0	0	0	0	3	9	8	8	7	7	4
39	1968	6	6	7	6	6	9	10	9	11	11	11	10	9
40	1969	10	10	11	11	10	11	16	16	16	16	16	16	13
41	1970	15	16	18	18	21	21	25	26	25	24	24	24	21
42	1971	23	23	22	22	21	21	24	26	25	25	24	23	23
43	1972	20	18	18	18	18	21	24	29	32	30	29	29	24
44	1973	28	28	31	34	36	41	42	36	33	34	35	35	35
45	1974	34	34	37	37	34	30	26	24	22	23	22	22	29
46	1975	22	21	22	21	22	23	17	15	16	16	16	17	19
47	1976	19	13	10	4	0	0	0	0	0	-2	-1	-2	3
48	1977	-2	-3	-3	-3	-4	1	4	3	3	3	2	2	0
49	1978	3	4	6	0	0	0	0	0	-1	-2	-3	-4	0
50	1979	-4	-5	-5	-4	-4	0	0	0	-2	-1	-2	-3	-3
	AVER	4	3	4	4	3	5	5	6	5	5	4	4	4

Table 6.11-32: DELTA VALUES QUABBIN RESER. END-OF-MONTH ELEV ,BOSTON CITY BASE)

RUN NY-13 06/07/85 MILLERS ALTERNATIVE (WITH TULLY) DM=11, DT=8 IOA= -1 0 0 1 0 -2

NY	NYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	12	12	13	13	13	15	14	12	12	12	12	12	13
2	98.0	12	12	12	13	12	10	11	12	11	12	12	12	11
3	96.0	11	11	11	11	10	10	10	12	11	11	12	11	10
4	94.0	10	9	9	9	10	9	10	11	10	10	10	10	10
5	92.0	8	8	9	9	9	9	9	8	8	8	8	8	10
6	90.0	7	7	8	7	7	8	7	7	7	7	8	8	6
7	88.0	6	6	6	6	5	6	6	6	5	5	5	6	6
8	86.0	5	5	6	5	5	6	6	6	5	5	5	5	5
9	84.0	5	5	5	5	5	6	6	5	5	5	5	5	5
10	82.0	5	4	4	5	5	5	5	5	5	5	5	5	4
11	80.0	4	4	4	4	4	4	5	5	5	5	5	5	4
12	78.0	3	3	3	4	4	4	4	4	4	4	4	4	4
13	76.0	3	3	3	3	3	4	4	4	4	4	4	3	4
14	74.0	3	3	3	3	3	4	4	4	3	4	4	3	3
15	72.0	3	3	3	3	3	3	3	4	3	3	3	3	3
16	70.0	3	3	3	2	2	3	2	4	3	3	3	3	3
17	68.0	1	1	2	1	1	1	2	2	2	2	2	2	2
18	66.0	1	1	1	1	0	1	1	2	2	2	1	1	1
19	64.0	1	1	1	1	0	1	1	1	1	1	1	1	1
20	62.0	1	1	1	1	0	1	1	1	1	1	1	1	1
21	60.0	1	1	0	1	0	0	1	1	1	1	1	1	1
22	58.0	0	0	0	0	0	0	1	0	0	0	0	0	0
23	56.0	0	0	0	0	0	0	1	0	0	0	0	0	0
24	54.0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	52.0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	50.0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	48.0	-1	0	0	0	0	0	0	0	0	0	0	0	0
28	46.0	-1	-1	0	0	0	0	0	0	0	0	0	0	0
29	44.0	-1	-1	-1	0	0	0	0	0	0	0	0	0	0
30	42.0	-1	-1	-1	0	0	0	0	0	0	0	-1	-1	0
31	40.0	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	0
32	38.0	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	0
33	36.0	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1
34	34.0	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1
35	32.0	-1	-1	-1	-1	-1	0	0	0	0	-1	-1	-1	-1
36	30.0	-1	-1	-1	-1	-1	-1	0	0	0	-1	-1	-1	-1
37	28.0	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
38	26.0	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
39	24.0	-1	-1	-2	-1	-1	-1	0	0	-1	-1	-1	-1	-1
40	22.0	-1	-1	-2	-2	-2	-1	0	0	-1	-1	-1	-1	-1
41	20.0	-1	-1	-2	-2	-2	-1	0	0	-1	-1	-1	-1	-1
42	18.0	-1	-1	-2	-2	-2	-1	-1	-1	-1	-1	-1	-1	-1
43	16.0	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1	-1	-1
44	14.0	-2	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1	-2
45	12.0	-2	-2	-2	-2	-2	-2	-1	-1	-1	-1	-2	-2	-2
46	10.0	-2	-2	-2	-2	-2	-2	-1	-1	-1	-1	-2	-2	-2
47	8.0	-2	-2	-2	-2	-2	-2	-1	-1	-1	-2	-2	-2	-2
48	6.0	-2	-2	-2	-2	-3	-3	-2	-1	-2	-2	-2	-2	-2
49	4.0	-2	-3	-3	-3	-3	-3	-2	-2	-2	-3	-2	-2	-2
50	2.0	-4	-4	-4	-5	-5	-4	-4	-4	-4	-4	-3	-3	-4
	AVER	1	1	1	1	1	2	2	2	2	2	2	2	2

Table 6.11-33: STREAMFLOW - MILLERS R. AT ERVING, MGD

RUN HY-13 06/07/85 MILLERS ALTERNATIVE (WITH TULLY) DM=11, DT=8 C= 2 8 9 1 0 2 NTS= 2 NTTS= 2 TYIELD= 338. MGD

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	58	94	94	188	200	336	408	239	173	177	67	58	174
2	1931	57	120	93	93	85	275	862	403	386	119	112	86	224
3	1932	111	110	256	407	440	380	960	284	115	91	66	92	274
4	1933	267	475	283	412	439	634	1452	275	151	72	114	414	413
5	1934	380	292	261	363	180	901	1151	403	342	111	100	223	393
6	1935	302	373	396	531	414	597	714	293	407	240	82	123	372
7	1936	88	157	184	463	203	2326	1074	281	162	97	102	98	439
8	1937	177	188	409	553	519	443	857	720	454	263	144	207	410
9	1938	197	447	476	588	550	492	605	403	527	723	524	1959	622
10	1939	459	337	848	346	319	780	1292	373	151	65	124	53	429
11	1940	48	192	225	98	104	267	1715	785	460	187	74	72	352
12	1941	66	240	298	252	334	263	527	254	121	116	58	79	216
13	1942	64	151	199	238	152	843	636	263	259	261	119	91	274
14	1943	142	406	384	387	282	528	753	537	270	97	145	87	335
15	1944	158	499	229	82	126	477	945	307	469	239	86	209	318
16	1945	146	167	300	326	245	741	751	614	478	488	229	176	390
17	1946	168	266	313	374	367	614	468	654	535	192	204	116	356
18	1947	217	111	119	250	459	462	968	606	315	138	95	91	318
19	1948	55	295	192	126	254	779	754	679	732	273	75	50	355
20	1949	56	187	154	412	494	521	610	346	100	58	38	52	251
21	1950	54	74	168	411	356	470	879	342	301	82	58	84	272
22	1951	69	283	386	471	832	618	962	332	256	283	264	173	407
23	1952	376	608	519	675	637	645	1122	535	300	125	158	119	483
24	1953	100	105	254	383	615	1092	1499	906	271	104	61	47	452
25	1954	101	227	487	270	311	490	649	805	264	148	119	294	347
26	1955	217	482	639	263	323	687	858	305	331	126	418	176	402
27	1956	831	1027	247	596	261	405	1594	900	262	87	42	124	531
28	1957	177	185	638	790	496	308	616	380	168	73	36	53	326
29	1958	49	126	334	454	392	497	1047	743	150	113	88	107	341
30	1959	146	182	220	317	195	520	938	376	156	145	57	110	280
31	1960	371	525	812	464	419	328	1976	589	456	224	237	411	566
32	1961	395	417	252	163	241	571	1205	560	278	143	87	136	370
33	1962	155	201	157	304	186	384	981	369	169	67	79	50	258
34	1963	265	336	229	169	145	397	882	301	128	56	38	46	249
35	1964	76	219	226	268	319	521	810	229	60	48	34	28	235
36	1965	59	52	82	74	143	235	477	184	84	40	37	39	125
37	1966	113	101	147	123	253	430	416	286	93	40	36	64	175
38	1967	133	270	167	200	194	239	1113	529	450	320	109	99	318
39	1968	131	177	363	221	309	696	544	311	552	219	64	53	303
40	1969	85	219	375	222	206	339	1077	384	286	136	358	221	325
41	1970	141	468	405	240	572	481	1062	526	417	105	83	91	380
42	1971	151	189	198	147	222	435	973	384	162	110	134	127	269
43	1972	155	223	496	501	324	666	1140	495	533	286	124	100	420
44	1973	135	385	487	509	538	706	971	765	442	333	173	107	462
45	1974	118	186	808	720	614	776	730	577	232	125	51	224	430
46	1975	251	334	415	446	353	741	969	289	319	292	280	405	424
47	1976	761	831	614	708	1194	921	735	581	157	139	175	91	572
48	1977	189	148	183	98	119	934	840	436	210	111	96	147	293
49	1978	500	482	591	933	486	547	1085	357	256	75	92	47	454
50	1979	97	72	177	787	370	1784	991	720	277	129	169	285	490
	AVER	192	285	336	368	356	610	933	464	293	166	126	168	357

Table 6.11-34: DELTA VALUES STREAMFLOW - MILLERS R. AT ERVING, PCT

RUN HY-13 06/07/85 MILLERS ALTERNATIVE (WITH TULLY) DM=11, DT=8 IOA= -1 0 0 3 0 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	98.0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	96.0	0	0	0	0	0	0	0	0	0	0	0	0	-1
4	94.0	0	0	0	0	0	0	0	0	0	0	0	0	-2
5	92.0	0	0	0	0	0	0	0	0	0	0	0	0	-2
6	90.0	0	0	0	0	0	0	0	0	0	0	0	0	-2
7	88.0	0	0	0	0	0	0	0	0	0	0	0	0	-3
8	86.0	0	0	0	0	0	0	0	0	0	0	0	0	-4
9	84.0	0	0	0	0	0	0	0	0	0	0	0	0	-4
10	82.0	0	0	0	0	0	0	0	0	0	0	0	0	-4
11	80.0	0	0	0	0	0	0	0	0	0	0	0	0	-4
12	78.0	0	0	0	0	0	0	0	0	0	0	0	0	-4
13	76.0	0	0	0	0	0	0	0	0	0	0	0	0	-5
14	74.0	0	0	0	0	0	0	0	0	0	0	0	0	-5
15	72.0	0	0	0	0	0	0	0	0	0	0	0	0	-5
16	70.0	0	0	0	0	0	0	0	0	0	0	0	0	-5
17	68.0	0	0	0	0	0	-2	0	0	0	0	0	0	-5
18	66.0	0	0	0	0	0	-3	0	0	0	0	0	0	-5
19	64.0	0	0	0	0	0	-4	0	0	0	0	0	0	-5
20	62.0	0	0	0	0	0	-6	0	0	0	0	0	0	-5
21	60.0	0	0	0	0	0	-10	0	0	0	0	0	0	-5
22	58.0	0	0	0	0	0	-12	0	0	0	0	0	0	-5
23	56.0	0	0	-1	0	0	-12	-1	-1	0	0	0	0	-6
24	54.0	0	0	-3	0	0	-13	-1	-2	0	0	0	0	-6
25	52.0	0	0	-4	0	0	-13	-2	-2	0	0	0	0	-6
26	50.0	0	0	-6	0	0	-13	-2	-5	0	0	0	0	-6
27	48.0	0	-1	-10	0	0	-15	-6	-6	0	0	0	0	-6
28	46.0	0	-2	-10	-2	0	-21	-8	-8	0	0	0	0	-6
29	44.0	0	-2	-11	-3	0	-21	-9	-9	0	0	0	0	-7
30	42.0	0	-2	-12	-4	0	-22	-9	-10	0	0	0	0	-7
31	40.0	0	-2	-14	-5	0	-25	-11	-10	0	0	0	0	-7
32	38.0	0	-3	-15	-7	0	-25	-13	-12	0	0	0	0	-7
33	36.0	0	-3	-15	-9	0	-27	-14	-12	-4	0	0	0	-7
34	34.0	0	-5	-16	-10	0	-28	-16	-13	-5	0	0	0	-7
35	32.0	0	-6	-17	-12	0	-28	-18	-16	-7	0	0	0	-7
36	30.0	0	-6	-17	-14	0	-28	-18	-16	-7	0	0	0	-8
37	28.0	0	-6	-19	-15	0	-29	-18	-16	-7	0	0	0	-8
38	26.0	0	-6	-20	-16	-4	-29	-19	-17	-7	0	0	0	-8
39	24.0	0	-6	-20	-17	-7	-30	-19	-19	-10	0	0	0	-8
40	22.0	0	-8	-24	-19	-9	-30	-20	-19	-11	0	0	0	-8
41	20.0	-1	-9	-24	-20	-13	-31	-20	-24	-11	0	0	0	-10
42	18.0	-2	-10	-26	-20	-15	-31	-21	-25	-14	0	0	0	-10
43	16.0	-2	-13	-26	-21	-21	-32	-21	-26	-15	0	0	0	-10
44	14.0	-3	-13	-26	-24	-21	-34	-22	-27	-18	-1	-1	0	-11
45	12.0	-5	-20	-27	-27	-23	-37	-23	-27	-21	-2	-1	-1	-11
46	10.0	-6	-22	-30	-29	-23	-37	-23	-38	-22	-5	-3	-5	-11
47	8.0	-17	-24	-31	-30	-27	-38	-24	-42	-24	-5	-5	-6	-12
48	6.0	-20	-25	-36	-33	-29	-39	-25	-45	-25	-8	-8	-16	-12
49	4.0	-22	-27	-40	-34	-29	-39	-26	-47	-27	-16	-21	-24	-12
50	2.0	-27	-30	-42	-36	-35	-41	-26	-49	-27	-28	-29	-44	-15
	AVER	-2	-5	-11	-8	-5	-16	-9	-11	-5	-1	-1	-2	-6

Table 6.11-35: DELTA VALUES STREAMFLOW - CHICOPEE R. AT INDIAN ORCHARD, MGD

RUN HY-13 06/07/85 MILLERS ALTERNATIVE (WITH TULLY) DM=11, DT=8 IOA= -1 0 0 1 1 2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1931	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1932	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1933	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	1934	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	1935	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1936	0.0	0.0	0.0	0.0	0.0	0.0	293.0	6.9	0.0	0.0	0.0	0.0	24.7
8	1937	0.0	0.0	0.0	0.0	123.3	0.0	0.0	-107.7	0.0	0.0	0.0	0.0	0.3
9	1938	0.0	0.0	0.0	0.0	48.6	82.1	4.4	0.0	0.0	-206.2	0.0	-36.0	-9.4
10	1939	-37.2	0.0	0.0	-3.1	-14.6	-24.7	0.0	10.2	0.0	0.0	0.0	0.0	-5.8
11	1940	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.8	0.0	0.0	0.0	0.0	1.7
12	1941	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	1942	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	1943	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	1944	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	1945	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	1946	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.8	0.0	0.0	0.0	0.0	1.9
18	1947	0.0	0.0	0.0	0.0	0.0	0.0	198.9	194.4	0.0	0.0	0.0	0.0	32.9
19	1948	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	148.1	0.0	0.0	0.0	12.2
20	1949	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	1950	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	1951	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	1952	0.0	0.0	0.0	0.0	217.4	224.6	506.3	53.2	0.0	0.0	0.0	0.0	81.9
24	1953	0.0	0.0	0.0	0.0	0.0	193.4	363.4	0.0	0.0	0.0	0.0	0.0	46.3
25	1954	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52.9	0.0	0.0	0.0	0.0	4.5
26	1955	0.0	0.0	180.8	0.0	0.0	-94.9	-15.2	0.0	0.0	0.0	0.0	0.0	6.0
27	1956	-52.4	0.0	0.0	-153.4	-16.5	-22.9	0.0	-36.8	-16.7	0.0	0.0	0.0	-25.2
28	1957	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	1958	0.0	0.0	0.0	0.0	0.0	0.0	0.0	174.0	0.0	0.0	0.0	0.0	14.8
30	1959	0.0	0.0	0.0	0.0	0.0	0.0	-82.2	0.0	0.0	0.0	0.0	0.0	-6.8
31	1960	0.0	0.0	-23.7	-14.7	0.0	0.0	-77.7	0.0	0.0	0.0	0.0	0.0	-9.7
32	1961	0.0	0.0	0.0	0.0	0.0	0.0	66.7	0.0	-4.5	0.0	0.0	0.0	5.1
33	1962	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	1964	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	1965	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	1966	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-57.0	-1.0	-4.9
38	1967	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	1969	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	1973	0.0	0.0	0.0	0.0	0.0	0.0	0.0	437.1	0.0	0.0	0.0	0.0	37.1
45	1974	0.0	0.0	0.0	0.0	232.4	364.1	223.5	115.1	0.0	0.0	0.0	0.0	76.9
46	1975	0.0	0.0	0.0	0.0	0.0	0.0	464.7	0.0	0.0	0.0	0.0	0.0	38.2
47	1976	0.0	452.1	324.2	425.1	364.9	-43.9	-26.8	-11.5	0.0	0.0	0.0	0.0	121.9
48	1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	1978	0.0	0.0	0.0	487.2	-8.4	-20.5	0.0	0.0	0.0	0.0	0.0	0.0	39.0
50	1979	0.0	0.0	0.0	0.0	0.0	-345.2	0.0	0.0	0.0	0.0	0.0	0.0	-29.3
	AVER	-1.8	9.0	9.6	14.8	18.9	6.2	38.4	18.6	2.5	-4.1	-1.1	-0.7	9.1

Table 6.11-36: DELTA VALUES STREAMFLOW - CONN. R. AT THOMPSONVILLE, CT., PCT

RUN HY-13 06/07/85 MILLERS ALTERNATIVE (WITH TULLY) DM=11, DT=8 IOA= -1 0 0 3 0 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0	3	3	4	2	2	2	2	1	0	0	0	1
2	98.0	0	0	1	3	2	2	1	1	0	0	0	0	0
3	96.0	0	0	0	0	2	1	1	1	0	0	0	0	0
4	94.0	0	0	0	0	1	1	1	1	0	0	0	0	0
5	92.0	0	0	0	0	0	0	1	0	0	0	0	0	0
6	90.0	0	0	0	0	0	0	1	0	0	0	0	0	0
7	88.0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	86.0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	84.0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	82.0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	80.0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	78.0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	76.0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	74.0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	72.0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	70.0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	68.0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	66.0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	64.0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	62.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
21	60.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
22	58.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
23	56.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
24	54.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
25	52.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
26	50.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
27	48.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
28	46.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
29	44.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
30	42.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
31	40.0	0	0	0	0	0	-1	0	0	0	0	0	0	0
32	38.0	0	0	-1	0	0	-1	0	0	0	0	0	0	0
33	36.0	0	0	-1	-1	0	-1	0	0	0	0	0	0	0
34	34.0	0	0	-1	-1	0	-1	0	0	0	0	0	0	0
35	32.0	0	0	-1	-1	0	-1	-1	0	0	0	0	0	0
36	30.0	0	0	-1	-1	0	-1	-1	0	0	0	0	0	0
37	28.0	0	0	-1	-1	0	-1	-1	0	0	0	0	0	0
38	26.0	0	0	-1	-1	0	-1	-1	-1	0	0	0	0	0
39	24.0	0	0	-1	-1	0	-1	-1	-1	0	0	0	0	0
40	22.0	0	0	-1	-1	-1	-1	-1	-1	0	0	0	0	0
41	20.0	0	0	-1	-1	-1	-2	-1	-1	-1	0	0	0	0
42	18.0	0	0	-1	-1	-1	-2	-1	-1	-1	0	0	0	0
43	16.0	0	0	-1	-1	-1	-2	-1	-1	-1	0	0	0	0
44	14.0	0	0	-1	-1	-1	-2	-1	-1	-1	0	0	0	0
45	12.0	0	-1	-1	-1	-1	-2	-1	-1	-1	0	0	0	0
46	10.0	0	-1	-1	-1	-1	-2	-1	-1	-1	0	0	0	0
47	8.0	-1	-1	-2	-1	-1	-2	-1	-1	-1	0	0	0	0
48	6.0	-1	-1	-2	-2	-1	-2	-1	-2	-1	-1	-1	-1	0
49	4.0	-1	-1	-2	-2	-1	-2	-1	-2	-2	-1	-1	-1	-1
50	2.0	-1	-1	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-1
	AVER	0	0	0	0	0	-1	0	0	0	0	0	0	0

6.12 FACILITY DESIGN

6.12.1 Descriptions of the Facility

I. Design Yield

- Transfer System. Two sub-alternatives have been studied and are presented in this report. The Millers River Alternative involves the transfer of water from the Millers River to Quabbin Reservoir during periods of high flow in the river. The Millers/Tully River Alternative involves the transfer of water from both the Millers River and the East Branch of the Tully River, to Quabbin Reservoir during periods of high flow in the rivers. Water would be diverted from these rivers to Quabbin through intake screens, shafts, tunnels and outlet works as shown on Drawing No. SK-T-001. Millers River intake facilities would include a bascule gate and weir across the width of the river at the location of the Miller intake shaft. Tully intake facilities would include a bascule gate across the width of the existing outlet channel of Tully Dam. Intake screens would be located in the river or channel just upstream of the bascule gates. Drawing Nos. SK-T-002 and SK-T-003 show details of the intake structures at the Millers and Tully Rivers. Drawing Nos. SK-T-004 and SK-T-005 show details of the two alternative outlet structures considered under this alternative.

- Operations. The diversion of water from the Millers and Tully Rivers to Quabbin Reservoir is accomplished by gravity flow through the tunnel system shown on Drawing No. SK-T-001. Approximately 104 to 118 feet of head is available to drive the water through the tunnel system. Diversions are made by raising the bascule gates (to be located in the Millers River and in the outlet channel from Tully Dam) and ponding water upstream of the bascule gates to Elevation 628 (USGS datum). This allows the intake screens (located upstream of the bascule gates as shown on Drawing Nos. SK-T-002 and SK-T-003) to become flooded and the diversion to begin. Water collected by the intake screens is carried by pipelines to the intake shafts and into the tunnel system.

  The diversion rate is controlled by motor-operated control valves located on the

pipelines between the intake screens and the intake shafts. The design includes automatic control systems which continually monitor the streamflows and diversion rates for both rivers, and adjust the control valves and bascule gates so that minimum streamflow requirements are met. To further assure that these requirements are met on the Millers River, a minimum flow channel has been provided adjacent to the bascule gate. The minimum flow channel will also act as a fish ladder to allow the movement of fish upstream. On a monthly basis, the slide gate in this channel will be adjusted to a pre-determined setting so that the minimum flow requirement can be passed through this channel. A level controller will be used to regulate the bascule gates setting so that the pool upstream of the bascule gates is maintained at Elevation 628 (USGS datum) at both intakes. When streamflow exceeds the minimum flow requirements, diversions will be made in the amount exceeding the minimum flow requirements, up to the capacity of the tunnel system. When the amount of water available for diversion exceeds the tunnel capacity, water will pass over the bascule gate. When streamflow is less than the minimum flow requirements, the level controller will be unable to maintain the upstream pool at Elevation 628 and the diversion will be curtailed by closing the control valves in the pipelines to the intake shafts.

A continuous recording device will be used to register and record pertinent data such as streamflow, bascule gate setting, setting of slide gate in minimum flow channel, diversion rate, and daily amount diverted. The diversion rate will be measured by acoustical transducers located in the transfer tunnel a short distance downstream of the Tully Shaft, and a short distance upstream and downstream of the Millers Shaft. The measuring and recording system at the Tully and Millers Intakes will be integrated so that composite records are also maintained.

- Diversion Limits. The MDC diversion of water is limited in two ways. Transfers can be made only on those days when the flow in the Connecticut River at the Montague Gage is greater than 17,000 cfs. Furthermore, there are minimum streamflow requirements in the Millers River which must be met (see Section 6.11) before diversions can be made. Diversions have been assumed to occur on

any day in which there is water available in excess of the above limits and when Quabbin is less than 98 percent full. This results in a year-round diversion period, however, approximately 60 percent of the total water diverted occurs during March, April and May.

- Transfer Rates. The system is designed to transfer up to 535 MGD for the Millers River Alternative and up to 690 MGD for the Millers/Tully River Alternative. For the Millers/Tully River Alternative, the maximum transfer rate from the Tully River is 412 MGD and the maximum transfer rate from the Millers River is 690 MGD. Actual diversion rates will depend on the amount of water available for diversion in excess of the minimum streamflow requirements.

- Yield. The hydrologic model for the Connecticut River Alternative, developed by Arthur D. Little, Inc., is described under Section 6.11. Results of the computer simulations indicate that the maximum potential yield is 55 MGD for the Millers River Alternative and 69 MGD for the Millers/Tully River Alternative. However, there are some times when Quabbin Reservoir is full on days when a diversion would be permitted. Since diversions would not be made on those days, the actual yield of this alternative is only 33 MGD for the Millers River Alternative and 38 MGD for the Millers/Tully River Alternative. The safe yield of the MDC's water supply system would be increased by these amounts through implementation of these alternatives.

The diversion of water under these alternatives relies to a large extent on the availability of the intake screens in the Millers River and in the outlet channel from Tully Dam. If these screens become blocked or damaged, the diversion rate would be affected. Air backwash systems are included in the design to prevent the accumulation of particulates and debris on the screens; however, one concern which has not been fully investigated is blockage due to freezing of the screens or due to frazil ice formation and lodging in the screen openings. While there may be some days during the winter months when icing may be a problem, there are other days during the year when diversions could be made to gain back water which is lost during the winter. (There are a number of days during the year on which streamflow is sufficient to allow a diversion but

Quabbin Reservoir is above 98 percent full and no diversion is made. This implies that there are "backup days" available during the year. Therefore, if days are lost in the winter due to icing of the screens, an equivalent amount of water could be transferred on days in other seasons of the year to make up for the lost amount.) Further hydrologic modeling and icing studies during the preliminary design phase of this Alternative are necessary to fully determine the impacts of this problem. However the impact on the yield of these alternatives is anticipated to be only slight, if at all.

II. Treatment and Transport Requirements

- Diversion Facilities. Two sub-alternatives were studied. The first, which is considered the base case for this study, would divert water only from the Millers River. The second would divert water from both the Millers River and Tully River. These two options are respectively referred to as the Millers River Alternative and the Millers/Tully River Alternative.

  The diversion facilities from the Millers River and Tully River to Quabbin Reservoir are shown on the appended drawings. For the Millers River Alternative, the facilities include:

  - Bascule gate, weir, and fish ladder across the Millers River,

  - Twenty, 72-inch diameter tee-type intake screens and piping to the Millers River Shaft,

  - Prefabricated building and associated facilities to house equipment required to backwash the screens, and valves and controls for monitoring and controlling the diversion flow,

  - the Millers River Shaft,

  - approximately 40,850 linear feet of 10-foot diameter tunnel (constructed with a tunnel boring machine) from the Millers River to Quabbin Reservoir with a construction shaft located near Athol, and

  - An outlet structure at Quabbin Reservoir.

For the Millers/Tully River Alternative, the facilities are the same, except that the tunnel from the Millers River Shaft to Quabbin would be 11 feet instead of 10 feet in diameter.

In addition, the following facilities are required:

- An 8 foot diameter tunnel (constructed with a tunnel boring machine), approximately 13,550 feet long, from the Millers River Shaft to the Tully Shaft,

- Tully Shaft,

- Bascule gate across the Tully Dam outlet channel,

- Twelve, 72-inch diameter tee-type intake screens and piping to the Tully Shaft, and

- A prefabricated building and associated facilities at the Tully Intake Shaft similar to that required at the Millers River.

Because the transfer of water is by gravity, the transfer capacity and yield of this alternative is dependent on the tunnel size. The hydrologic model was run to determine the yield of each sub-alternative at various tunnel sizes. Marginal cost analyses were performed to determine the most appropriate tunnel sizes for each sub-alternative. Those sizes appear to be 10 feet for the Millers to Quabbin tunnel under the Millers River Alternative, 11 feet for the Millers to Quabbin tunnel under the Millers/Tully River Alternative, and 8 feet for the Tullys to Millers tunnel under the Millers/Tully River Alternative.

Two alternate outlet schemes were developed under this study. They are: a direct tunnel outlet scheme and a deep channel outlet scheme. Their locations are shown on Drawing No. SK-T-001. They are detailed on Drawing Nos. SK-T-002 and SK-T-003. The direct tunnel outlet scheme has been assumed as the base case for the cost estimates. Cost estimates are presented in Section III for both. The deep channel outlet scheme appears to be less expensive.

- Treatment. The quality of the Millers River water and Tully River water to be diverted to

Quabbin Reservoir has been assessed. That assessment is presented in Section 6.20 of this report. The water quality parameters of major concern are turbidity, phosphorus, nitrogen and coliform bacteria. The assimilative capacity of Quabbin Reservoir is expected to be sufficient to reduce these parameters to levels within the state and federal drinking water limits. Therefore, no water treatment facilities are included for this alternative.

Also of concern is the potential introduction of undesirable fish and eels into Quabbin Reservoir. Intake screens with a quarter inch slot opening are used to control the introduction of these species into the diversion system. The level to which the screens will prevent the introduction of undesirable species into Quabbin has not been fully assessed. Any significant adverse impacts will be addressed in the study under mitigating measures.

III. Cost Estimates.

Order-of-magnitude capital and operating and maintenance cost estimates were developed for both the Millers River and the Millers/Tully River Alternatives. Costs for the Millers River Alternative are presented in Table 6.12-1. Costs for the Millers/Tully River Alternative are presented in Table 6.12-2. The estimated accuracy of the order-of-magnitude cost estimates is ±30 percent. All costs are on a July 1982 basis.

- Capital Costs. Capital costs include construction costs; contingency; contractor's overhead and profit; engineering and construction management fees; land acquisition and right-of-way costs; legal, fiscal, and administrative fees; and interest during construction. The total capital cost is estimated to be $83,300,000 for the Millers River Alternative and $112,530,000 for the Millers/Tully River Alternative. Approximately 90 percent of this cost is for the tunnels and shafts.

  The foregoing costs are based on the direct the tunnel outlet scheme (assumed as the base case). This scheme happens to be more expensive than the deep channel outlet scheme also studied. The total capital cost for the deep channel outlet scheme is presented at the bottom of Tables 6.12-1 and 6.12-2. While it appears that the deep

TABLE 6.12-1: COSTS FOR THE MILLERS RIVER ALTERNATIVE

CAPITAL COSTS

Metering and Water Quality Monitoring	$ 60,000
Millers River Intake Structure	4,490,000
Shafts	3,480,000
Tunnels	48,520,000
Outlet Structure and Channel	1,300,000
Spoil Piles and Contractors Work Areas	520,000
Total Construction Cost, including Contractor's Overhead and Profit (18)	58,370,000
Contingency	8,760,000
Engineering and Construction Management Fees (03)	6,710,000
Land and Right-of-Way Costs (18)	20,000
Legal, Fiscal and Administrative Fees (03)	180,000
Interest During Construction (19)	9,260,000
TOTAL CAPITAL COST	$ 83,300,000

ANNUAL OPERATING AND MAINTENANCE COSTS

Energy Cost (08)	$ 5,000
Labor Cost (01)	150,000
Materials Cost (12)	25,000
Chemical Cost (07)	0
Waste Disposal Cost (08)	0
Replacement Cost (12)	75,000
TOTAL ANNUAL O&M COST	$ 255,000

ANNUAL COST AND UNIT COST OF WATER

First Year Amortized Capital and O&M Cost	$ 5,578,000
Unit Cost of Water for First Year of Operation	$463/MG
Net Present Value/Actual Water Yield	$142/MG

Notes:
1. The estimated accuracy of these cost estimates is ± 30 percent.
2. Numbers in parentheses, e.g. (18), refer to the Commonwealth of Massachusetts, Subsidiary Accounts and Expenditure Codes for Budgetary Control.
3. The capital costs are based on the Direct Tunnel Outlet Scheme. The total capital cost of the Deep Channel Outlet Scheme is $80,890,000.
4. All costs are expressed in July 1982 dollars.

TABLE 6.12-2: COSTS FOR THE MILLERS/TULLY RIVER ALTERNATIVE

CAPITAL COSTS

Metering and Water Quality Monitoring	$ 90,000
Tully Lake Intake Structure	2,920,000
Millers River Intake Structure	4,490,000
Shafts	4,160,000
Tunnels	65,210,000
Outlet Structure and Channel	1,300,000
Spoil Piles and Contractors Work Areas	680,000
Total Construction Cost, including Contractor's Overhead and Profit (18)	$78,850,000
Contingency	11,830,000
Engineering and Construction Management Fees (03)	9,070,000
Land and Right-of-Way Costs (18)	30,000
Legal, Fiscal and Administrative Fees (03)	250,000
Interest During Construction (19)	12,500,000
TOTAL CAPITAL COST	$112,530,000

ANNUAL OPERATING AND MAINTENANCE COSTS

Energy Cost (08)	$ 5,000
Labor Cost (01)	270,000
Materials Cost (12)	30,000
Chemical Cost (07)	0
Waste Disposal Cost (08)	0
Replacement Cost (12)	120,000
TOTAL ANNUAL O&M COST	$ 425,000

ANNUAL COST AND UNIT COST OF WATER

First Year Amortized Capital and O&M Cost	$ 7,602,000
Unit Cost of Water for First Year of Operation	$548/MG
Net Present Value/Actual Water Yield	$170/MG

Notes:
1. The estimated accuracy of these cost estimates is ± 30 percent.
2. Numbers in parentheses, e.g. (18), refer to the Commonwealth of Massachusetts, Subsidiary Accounts and Expenditure Codes for Budgetary Control.
3. The capital costs are based on the Direct Tunnel Outlet Scheme. The total capital cost of the Deep Channel Outlet Scheme is $109,860,000.
4. All costs are expressed in July 1982 dollars.

channel outlet scheme would be preferred from a cost standpoint, the environmental impacts of these schemes have not yet been assessed.

Land values in this part of Massachusetts range from $400 to $5,000 per acre. Costs have been included for the acquisition of 19 acres of land for the Millers River Alternative and 32 acres of land for the Millers/Tully River Alternative. The land costs was estimated at $1,000 per acre. For the Millers River Alternative, this area is comprised of approximately 2 acres for the intake structure, a half acre for access to shafts, and 16½ acres for the spoil piles. For the Millers/Tully River Alternative, the area is the same as above except for 1 additional acre of land required for the Tully intake structures and 12 additional acres of land for the spoil piles at Tully Dam and the Millers River. A maximum average spoil height of approximately 9 feet would be expected in the spoil pile area near the Athol shaft, for the Millers/Tully River Alternative.

Facilities on MDC-owned land are assumed to have no cost and are not included in the above land requirements.

Right-of-way costs were calculated using $500 per acre (a rate equal to half of the cost of purchasing the land) for permanent easements and $300 per acre for temporary easements. Temporary easements would be required for all areas which would be used during the construction period (construction access roads and contractor work areas). Permanent easements would be required for permanent access to the intake structures. Temporary and permanent easement and land acquisition requirements are shown in Table 6.12-3 and 6.12-4.

- Operation, Maintenance and Replacement Costs. Operating and maintenance costs include costs of energy, labor and consumable items (including materials and chemicals), and replacement costs required to operate and maintain the facilities. The total annual operating and maintenance cost of this Alternative is estimated to be $255,000 per year for the Millers River Alternative, and $425,000 per year for the Millers/Tully River Alternative. Over 95 percent of this cost is for the operation of the intake works and water quality monitoring facilities.

TABLE 6.12-3: LAND ACQUISITION AND EASEMENT REQUIREMENTS (MILLERS RIVER ALTERNATIVE)

LOCATION	LAND ACQUISITION (ACRES)	PERMANENT EASEMENT (ACRES)	TEMPORARY EASEMENT (ACRES)
Millers River Intake Structure	2.0	0.5	2.0
Athol Shaft	0.5	0	2.0
Quabbin Outlet Structure and Shaft	N/A	N/A	N/A
Millers Spoil Pile	4.5	0	0
Athol Spoil Pile	12.0	0	0
Quabbin Spoil Pile	N/A	N/A	N/A
TOTAL	19.0	0.5	4.0

Notes.
1. N.A. means not applicable because these areas are within lands currently owned by the MDC.
2. Permanent easements are for permanent access roads where not on MDC-owned land. No cost has been assumed for subsurface easements for tunnels.
3. Temporary easements have been assumed for areas required only during construction of the facilities.

TABLE 6.12-4: LAND ACQUISITION AND EASEMENT REQUIREMENTS
(MILLERS/TULLY RIVER ALTERNATIVE)

LOCATION	LAND ACQUISITION (ACRES)	PERMANENT EASEMENT (ACRES)	TEMPORARY EASEMENT (ACRES)
Tully Intake Structure and Shaft	1.0	0.5	1.0
Millers River Intake Structure and Shaft	2.0	0.5	2.0
Athol Shaft	0.5	0	2.0
Quabbin Outlet Structure and Shaft	N/A	N/A	N/A
Tully Spoil Pile	1.5	0	0
Millers Spoil Pile	15.0	0	0
Athol Spoil Pile	12.0	0	0
Quabbin Spoil Pile	N/A	N/A	N/A
TOTAL	32.0	1.0	5.0

Notes.
1. N.A. means not applicable because these areas are within lands currently owned by the MDC.
2. Permanent easements are for permanent access roads where not on MDC-owned land. No cost has been assumed for subsurface easements for tunnels.
3. Temporary easements have been assumed for areas required only during construction of the facilities.

In calculating the unit cost of water (reported elsewhere in this study), an annual allowance was included for replacement of equipment and facilities over the forty year study period. This allowance (which could be considered as a sinking fund for replacement and major repairs) has been estimated to be $75,000 per year for the Millers River Alternative and $120,000 per year for the Millers/Tully River Alternative.

- Construction Scheduling Considerations. Design, procurement and construction of the facilities required for the Millers/Tully River Alternative will take several years, even after completion of this Environmental Impact Report process. If the Millers/Tully River Alternative is selected for implementation, it is likely that it would not be operational before 1990.

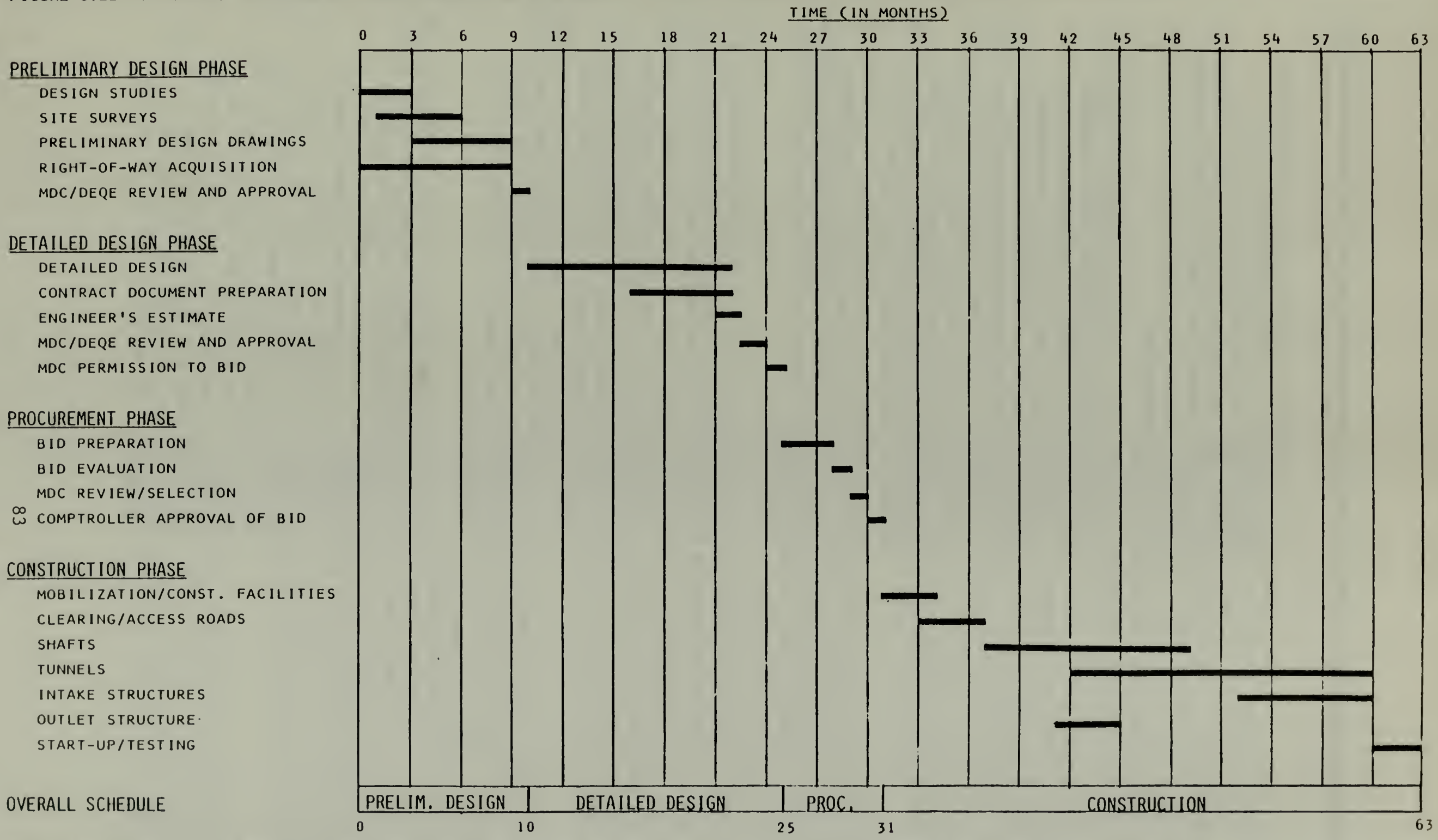
  Figure 6.12-1 presents a preliminary schedule for design, procurement and construction of the facilities required for this alternative. The overall duration is 63 months (5 years and 3 months). The design phase would require 25 months; the procurement phase would require 6 months; and the construction phase would require 32 months. The longest single activity on the schedule is the construction of the tunnels which is estimated to take 18 months. The construction schedule would be the same for either the Millers River Alternative or the Millers/Tully River Alternative since construction of the additional facilities for Tully River would occur at the same time as the tunnel from Millers River to Quabbin section.

IV. Noncost Considerations.

Numerous considerations will go into the selection of the preferred alternative for augmenting the MDC Water Supply. Some of the more obvious considerations are: the yield of the alternative, the cost of water supplied by the alternative, and the anticipated impacts of the alternative. However, there are other important factors which need to be taken into consideration. Two of those factors are reliability and flexibility of the supply alternative.

- Reliability. In the context of this report, reliability is defined as the ability of the water supply alternative to provide a dependable supply of water to the MDC system.

FIGURE 6.12-1: DESIGN, PROCUREMENT AND CONSTRUCTION SCHEDULE



NOTE: APPROXIMATELY 6-8 MONTHS IS REQUIRED BEFORE THE PRELIMINARY DESIGN PHASE FOR PROCUREMENT OF A DESIGN CONSULTANT.

In assessing the reliability of a water supply alternative, three components need to be addressed - the reliability of the source of supply, the reliability of the water transmission facilities between the supply and the existing MDC water system, and the susceptibility of loss due to contamination.

In general, the groundwater sources being studied by the MDC can be considered more reliable sources of water than the surface water sources. Groundwater supplies draw from underground reserves of water on a somewhat continuous basis. The surface water supplies being considered draw from natural streamflow, during periods when the streamflow is high enough to allow diversion. The quantity of water being supplied by the surface water sources is highly dependent on the magnitude and duration of high flows in the rivers being considered for diversion; whereas the availability of water from a groundwater source is dependent on the characteristics of the aquifer (e.g. transmissibility, storage capacity and recharge).

The reliability of the yield of the Millers/Tully River Alternative is highly dependent on the magnitude of the streamflow in the Millers River and Tully River, the frequency of high streamflow conditions and the timing of high streamflows with respect to full reservoir conditions at Quabbin. However, both the Millers and Tully River have flood control dams on them which should increase the reliability of these sources to a certain degree. These facilities would only be expected to equalize the flow over short periods of time, however, and not over long drought periods.

While the supply element of this alternative can be considered somewhat less reliable than that for a groundwater supply (Plymouth Aquifer Alternative) being considered by the MDC, the withdrawal and transmission elements can be considered somewhat more reliable. This alternative depends to a very small extent on the use of mechanical equipment to transfer the water. Therefore, there is a high degree of reliability in the transfer system. The water would be introduced into the system through intake screens and header pipes located in the Millers River or Tully Dam outlet channel. The water would be ponded in the river and the

channel by raising bascule gates. Water from the ponds behind the gates would be diverted through the intake screens and header pipes to the intake shafts. Only blockage of the screens or damage to the bascule gate system would prevent or severely limit the diversion. However, an air backwash system has been incorporated into the design. Therefore, blockage could be controlled by backwashing of the intake screen. As a result, the intake system can be considered very reliable. Likewise, the remaining elements of the transfer system (tunnels, shafts, gates and channels) have a very high reliability, especially since the flow of water to Quabbin Reservoir is by gravity. For that matter, the flow of water from Quabbin Reservoir to the water distribution systems in user communities is also by gravity.

Chemical contamination poses a threat to water supply sources. In the case of groundwater supplies, contamination can have long-term repercussions. While chemical contamination is a problem for both surface water and groundwater sources, it normally can be more easily and rapidly eliminated from surface water sources than from groundwater sources. Decontamination of groundwater supplies requires extensive measures, usually including isolation of the source of contamination and pumping of the contaminated portion of the groundwater supply to waste in order to remove all contamination from the aquifer.

In the northeastern United States, numerous groundwater supplies have been lost to chemical contamination in recent years. Examples within the MDC service area include the White Lodge Well Supply in Dedham and the Ellis Avenue Well Supply in Norwood. Most commonly, the sources lost to contamination are located in highly developed and urbanized areas. Some potential sources of contamination are: illegal industrial discharges, uncontrolled leachate from landfills, and pollutant laden infiltration from farm or park areas which have been treated with fertilizers or pesticides.

Contamination of the Miller River and Tully River would be a particularly serious condition for this alternative because no treatment is being provided for the water that is transferred to Quabbin Reservoir. Fortunately, the river

watershed areas, upstream of the diversion points, are not heavily developed areas. Potential sources of contamination are: discharges from upstream wastewater treatment plants (outside the limits of their NPDES permit), and chemical fertilizers, pesticides and herbicides introduced with runoff from adjacent farmland. Except for these possible sources of contamination, this rural setting provides excellent protection of the source from possible contamination. Barring no major, adverse development (industrial parks, landfills, etc.) in close proximity to these rivers, they should provide a low susceptibility to contamination and the contamination would be of relatively short duration; especially compared to the local sources of supply being studied under the User Sources Alternative.

- Flexibility. In this case, flexibility is defined as the capability of responding or conforming to changing or new conditions. As mentioned above, groundwater supplies draw from underground reserves of water. On a long-term basis, these underground reserves tend to respond to the long-term amount of water withdrawn, as opposed to the rate and frequency of the withdrawal (within reason). Therefore, a groundwater source has a flexibility that the surface water sources do not have (without providing reservoir storage). That is, water can be supplied by the groundwater source on somewhat of an as-needed basis within the design capacity of the system. It is not limited to only those times when other factors are present (e.g. high streamflows). This is a marked advantage of the groundwater alternatives being studied (Plymouth Aquifer and User Sources).

6.13 ENERGY CONSIDERATIONS

The annual energy cost constitutes only a very small portion of the total annual operating and maintenance cost for this alternative. Tables 6.12-1 and 6.12-2 shows the annual energy costs and the total annual operating and maintenance costs for this alternative. The annual energy cost amounts to approximately 2 percent of the total annual operating and maintenance cost. In fact, the total operating and maintenance cost for this alternative is very low itself.

Because the energy costs constitute approximately 2 percent of the total operating and maintenance costs, the total operating and maintenance cost will not be very sensitive to a change in the cost of energy. If the cost of energy doubles, the total operating and maintenance costs would increase by approximately 2 percent. This assumes that all other components of the total operating and maintenance cost (i.e. labor, materials and chemicals) remain the same. If the cost of energy were to increase at a rate slightly faster than the other components increase, the percentage change in the operating and maintenance cost would be only slightly more.

While energy costs can fluctuate quite significantly, depending on the price of nuclear, oil and coal fuels; in general, current projections are that energy costs will increase with time at a rate commensurate with the rate of increase in the other components of the total operating and maintenance costs. Increases in the cost of energy would need to be far out of scale with the increases of the other operating and maintenance costs for any sensitivity of operating and maintenance costs to the change in energy to be noticed.

In summary, energy costs do not constitute a significant portion of the total operating and maintenance costs for this alternative. In addition, it is believed that energy costs will increase generally at the same rate as the other components of the total operating and maintenance cost.

BIBLIOGRAPHY

Ashendon, David D., Metropolitan District Commission, Geology of the Proposed Northfield-Quabbin Tunnel, March 1973.

Bechtel, Inc., Northfield Water Supply Project Environmental Impact Report, Potential Connecticut and Millers River Alternative Periods and Operations, July 1981.

Wallace, Floyd, Ellenzweig, Moore, Inc., et.al, Northfield Water Supply Project Environmental Impact Report, Phase I Basic Services, Technical Memorandum Appendix, August 1980.

U.S. Army Corps of Engineers, Northeastern United States Water Supply Study, Northfield Mountain Water Supply Project, October 1974.

U.S. Army Corps of Engineers, Northeastern United States Water Supply Study, Millers River Basin Water Supply Project, October 1974.

U.S. Army Corps of Engineers, Connecticut River Basin, Master Manual of Reservoir Regulation Appendix F - Millers River Watershed - Birch Hill Dam and Tully Lake, May 1974.

6.14 POTENTIAL IMPACTS ON HYDROPOWER PRODUCTION

Introduction

The purpose of this section is to assess the impact of the Millers/Tully River Alternative on hydropower production. The only hydropower facilities affected are the MDC hydropower plants. These facilities are briefly discussed below.

MDC Hydropower Facilities

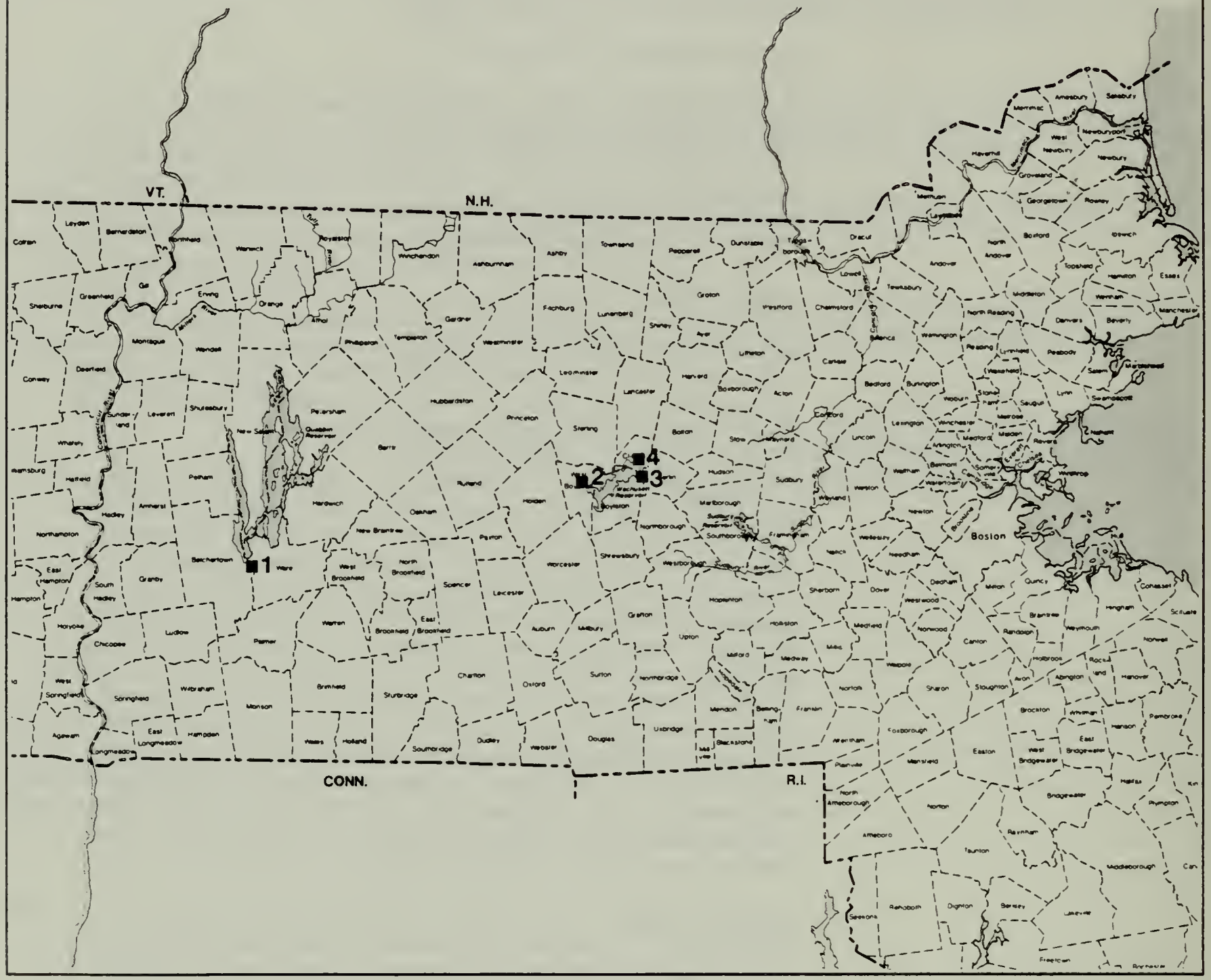
Presently the MDC has four hydroplants within its transmission and distribution system (See Figure 6.14-1, Existing MDC Hydropower Plants); three of these are currently in operation. The three operating plants are located at the Winsor Dam (Winsor Dam Plant), the Quabbin Aqueduct discharge to the Wachusett Reservoir (Oakdale Plant), and the Wachusett Reservoir Intake leading to the Wachusett-Marlborough Tunnel (Cosgrove Plant). The fourth plant, which is located at the Wachusett Dam, is not currently utilized. A fifth hydropower plant is presently under consideration and would be located on the transfer line between the Hultman and Weston Aqueducts near MDC Shaft 4 in Southborough, Massachusetts.

Winsor Dam Plant - The Winsor Dam hydroplant consists of one 1200 kW generator powered by two Francis turbines operating at 145 feet of head. This plant, which is powered by flow released from the Quabbin Reservoir, is located at the Winsor Dam outlet to the Swift River. A minimum release of 20 MGD (31 cfs) is required for the months of December through May. A minimum release of 71 MGD (110 cfs) is required for the months of June through November during low flow conditions in the Connecticut River. Discharges to the Swift River seldom exceed minimum release requirements due to the demand on the reservoir for water supply. However, to operate the turbines at maximum efficiency, a discharge rate of 110 cfs is maintained until the minimum daily flow is reached. Discharge is then discontinued until the next day.

Oakdale Plant - The Oakdale hydroplant consists of one 3500 kW generator powered by a Francis turbine operating at approximately 115 feet of head. This plant, which is powered by the flow from the Quabbin Reservoir, is located at the outlet of the Quabbin Aqueduct. Electrical production is approximately 70 MWH per day when operating. The operating period, which is dependent on yearly flow requirements, currently averages approximately 200 days per year.

MDC Plants

1 Winsor Dam Plant
2 Oakdale Plant
3 Cosgrove Plant
4 Wachusett Dam Plant

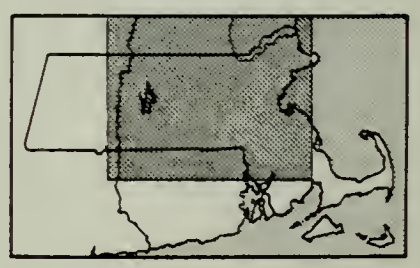


Legend

■1 Location of hydropower facilities. See key above for name of each plant.

Figure 6.14-1.
MDC Hydropower Plants

0 5 10 20 miles



Cosgrove Plant - The Cosgrove hydroplant consists of two 1680 kW generators powered by two Kaplan turbines operating at 80 feet of head. This plant is located at the Wachusett/Marlborough Tunnel intake. All water delivered from Quabbin and Wachusett Reservoirs to the Boston Metropolitan Area must pass through this plant. The flow from Wachusett Reservoir is currently, essentially continuous at approximately 270 to 300 MGD. Electricity production is approximately 46 MWH per day.

Wachusett Dam Plant - The Wachusett Dam hydroplant consists of four 1000 kW generators powered by four Francis turbines. These units which are located on the Wachusett Aqueduct to Sudbury Reservoir are not currently operated since the Wachusett Aqueduct is no longer used. A 1976 study (Vanderweil, 1976) reported that these units were still in excellent condition and the MDC has considered bringing them back on line for power production purposes. However, since the plant is not operating, no assessment of potential impacts will be made.

Weston/Hultman Aqueduct Plant - The proposed Weston/Hultman Aqueduct hydroplant would make use of the head difference between the Hultman Aqueduct and Weston Aqueduct flow transfer to generate power. This plant will generate the same amount of electricity, with and without this alternative. Therefore, there will be no impact on hydropower production at this plant.

Assessment of Impacts on Hydropower Production

Methodology

In the design of the Millers/Tully River Alternative two subalternatives were studied. These were diversion of the Millers River alone and diversion of the Millers River and Tully River at Tully Dam. Safe yield model runs were obtained for the Millers/Tully River Alternative for each of the two subalternatives. In addition, the model was run for a condition where there was no diversion of water. Using the fifty year monthly average data from the safe yield model, an estimate of hydropower generation for each of the plants was made. The difference in hydropower generation for the condition with the subalternative operating and with the subalternative not operating would represent the impact on hydropower production. Specific assumptions used in estimating the impact to hydropower production of the two subalternative diversion rates versus the case of no diversion are discussed below.

Winsor Dam Plant - In determining the impact to hydropower production the following assumptions were made for the Winsor Dam Plant: overall plant efficiency of 77 percent,

tailwater elevation of 385 ft. (Boston City Base); energy rate of 0.027 $/kWhr; and a maximum flow capacity of 71 MGD. The energy rate is based on the average of rates reported for 1982 through 1985, expressed in 1982 dollars. For diversion from the Millers River alone, on average, Quabbin Reservoir elevations would be higher and flows from Quabbin Reservoir at Winsor Dam would be generally higher. The total effect is an average annual increase in hydropower production of 581,000 kWhr/yr. At the above energy rate this results in an increase in revenues of $16,000/yr. For diversion from the Millers and Tully Rivers, hydropower production increases by 718,000 kWh/yr and revenues increase by $19,000/yr.

Oakdale Plant - In determining the impact to hydropower production, the following assumptions were made for the Oakdale Plant: overall plant efficiency of 70 percent; energy rate of 0.027 $/kWhr; and a maximum flow capacity of 325 MGD. The energy rate is based on the average of rates reported for 1982 through 1985, expressed in 1982 dollars. The tailwater elevation is approximately El. 395 ft. (Boston City Base). MDC reports that in order to be able to transfer more than 325-330 MGD of water from Quabbin Reservoir to Wachusett Reservoir, the Oakdale Hydroplant must by totally bypassed. Therefore, it was assumed that when transferring more than 325 MGD from Quabbin to Wachusett Reservoirs, the hydroplant would be bypassed and no hydropower would be produced. As a result, about 11 or 12 percent of the time, flow transferred would not be used for hydropower production. For this alternative, on average, Quabbin Reservoir elevations would be higher, flows from Quabbin Reservoir to Wachusett Reservoir would be greater, but during 11 or 12 percent of the time, the hydroplant would be bypassed. The net effect for diversion from the Millers River alone is an average annual decrease in hydropower production of 246,000 kWhr/yr. At the above energy rate, this results in an decrease in revenues of $6,600/yr. For diversion from the Millers and Tully River, hydropower production decreases by 45,000 kWhr/yr and revenues decrease by $1,200/yr.

Cosgrove Plant - In determining the impact to hydropower production the following assumptions were made for the Cosgrove Hydroplant: overall plant efficiency of 75 percent; and tailwater elevation of 316 ft. (Boston City Base). The power produced is sold equally to two local utilities. The energy rate used was 0.0295 $/kWhr. This is based on the average of rates reported from 1982 through 1985, expressed in 1982 dollars, for the two utilities. For this alternative, on average, Wachusett Reservoir elevations would be slightly less but the flow from Wachusett Reservoir would be substantially increased. The net effect for diversion from the Millers River alone is an

average annual increase in hydropower production of 2,000,000 kWhr/yr. At the above energy rate, this results in an increase in revenues of $59,000/yr. For diversion from the Millers and Tully River, hydropower production increases by 2,300,000 kWhr/yr and revenues increase by $68,000/yr.

Summary of Impacts

Tables 6.14-1, and 6.14-2 present the estimated impacts to hydropower for the Millers/Tully River Alternative with a diversion from only the Millers River and the Millers and Tully Rivers, respectively. From these tables, it is indicated that an overall increase in MDC hydropower production is expected from the Millers/Tully River Alternative.

For diversion from the Millers River only, a net increase in revenue of approximately $68,000/yr (1982 dollars) is expected. For diversion from the Millers and Tully River, a net increase in revenue of approximately $86,000/yr (1982 dollars) is expected.

TABLE 6.14-1 MILLERS / TULLY ALT.- MILLERS RIVER DIVERSION ONLY

Impact to Hydropower Generation

Hydroplant	Oct (kWh/ac)	Nov (kWh/ac)	Dec (kWh/ac)	Jan (kWh/ac)	Feb (kWh/ac)	Mar (kWh/ac)	Apr (kWh/ac)	May (kWh/ac)	Jun (kWh/ac)	Jul (kWh/ac)	Aug (kWh/ac)	Sep (kWh/ac)	Annual (kWh/yr)
Winsor Dam Plant	(13,266)	77,293	89,804	131,954	127,357	75,686	7,741	91,723	32,245	(31,760)	(7,867)	(633)	581,078
Oakdale Hydroplant	170,147	174,913	180,539	148,130	170,455	111,977	48,236	165,894	(57,947)	(273,744)	(801,963)	(282,129)	(246,193)
Cosgrove Hydroplant	186,517	176,815	161,927	165,924	146,358	155,324	149,223	160,293	128,726	199,489	159,645	146,728	1,996,894
Net Impact	343,398	429,022	432,269	446,008	444,170	342,988	205,200	417,115	163,024	(106,895)	(649,285)	(136,034)	2,331,779

Impact to Hydropower Revenues

Hydroplant	Oct ($/ac)	Nov ($/ac)	Dec ($/ac)	Jan ($/ac)	Feb ($/ac)	Mar ($/ac)	Apr ($/ac)	May ($/ac)	Jun ($/ac)	Jul ($/ac)	Aug ($/ac)	Sep ($/ac)	Annual ($/yr)
Winsor Dam Plant	(358)	2,087	2,425	3,563	3,439	2,044	209	2,477	871	(858)	(191)	(17)	15,689
Oakdale Hydroplant	4,594	4,723	4,875	3,999	4,602	3,023	1,302	4,458	(1,565)	(7,391)	(21,650)	(7,617)	(6,647)
Cosgrove Hydroplant	5,502	5,216	4,777	4,895	4,318	4,582	4,402	4,729	5,567	5,883	4,710	4,328	58,908
Net Impact	9,738	12,026	12,076	12,457	12,358	9,649	5,913	11,663	4,873	(2,366)	(17,132)	(3,306)	67,950

TABLE 6.14-2 MILLERS / TULLY ALT.- MILLERS / TULLY RIVER DIVERSION

Impact to Hydropower Generation

Hydroplant	Oct (kWh/ac)	Nov (kWh/ac)	Dec (kWh/ac)	Jan (kWh/ac)	Feb (kWh/ac)	Mar (kWh/ac)	Apr (kWh/ac)	May (kWh/ac)	Jun (kWh/ac)	Jul (kWh/ac)	Aug (kWh/ac)	Sep (kWh/ac)	Annual (kWh/yr)
Winsor Dam Plant	(13,148)	92,207	100,603	152,315	175,205	72,104	10,321	141,848	29,122	(36,495)	(5,602)	275	718,343
Oakdale Hydroplant	194,988	208,992	210,584	178,209	198,762	134,815	66,449	198,284	12,209	(288,185)	(781,869)	(369,103)	(44,865)
Cosgrove Hydroplant	212,571	201,437	186,997	191,638	169,308	178,411	171,974	184,450	218,974	232,467	189,128	173,430	2,310,777
Net Impact	394,412	494,636	498,185	522,162	543,273	384,529	248,744	523,782	260,185	(92,123)	(598,351)	(195,398)	2,983,955

Impact to Hydropower Revenues

Hydroplant	Oct ($/ac)	Nov ($/ac)	Dec ($/ac)	Jan ($/ac)	Feb ($/ac)	Mar ($/ac)	Apr ($/ac)	May ($/ac)	Jun ($/ac)	Jul ($/ac)	Aug ($/ac)	Sep ($/ac)	Annual ($/yr)
Winsor Dam Plant	(353)	2,498	2,716	4,113	4,730	1,947	279	3,808	786	(983)	(151)	7	19,387
Oakdale Hydroplant	5,265	5,427	5,686	4,812	5,367	3,618	1,794	5,354	324	(7,781)	(21,110)	(9,966)	(1,211)
Cosgrove Hydroplant	6,271	5,942	5,516	5,653	4,995	5,263	5,073	5,441	6,468	6,858	5,579	5,116	68,168
Net Impact	11,181	13,859	13,918	14,577	15,092	10,828	7,146	14,603	7,578	(1,906)	(15,683)	(4,842)	86,344

6.20 WATER QUALITY

In this chapter, the focus is on the water quality of the Millers and Tully Rivers and the Quabbin, Wachusett and Sudbury Reservoirs. Detailed baseline water quality data of Quabbin and Wachusett Reservoirs are included in the Task 4: No Action Assessment Report, Section 4.20 and in the Task 4: Interim Technical Report, Determination of the Quabbin Reservoir Minimum Pool Level. Detailed data on the water quality of Sudbury Reservoir are included in the Task 9: Upper Sudbury River Watershed Assessment Report, Section 9.20.

6.21 WATER QUALITY OF MILLERS/TULLY RIVERS

6.21.1 Baseline Conditions

I. Existing Conditions

- Water Quality

- Data Sources and Extent - Like the Connecticut River, a significant amount of water quality data has been generated for the Millers/Tully Rivers in the past decade. Table 6.21-1 summarizes the historic water quality data available from various agencies and used in this study. In addition, the sampling stations associated with each data collection program are listed and presented in Figure 6.21-1. No additional surface water quality data were collected during this study.

- Water Quality Parameters - The water quality parameters included in the determination of the baseline water quality of the Millers/Tully Rivers are presented in Table 6.21-2. These parameters were selected based on public health, aquatic habitat, and aesthetics considerations (New England Research, Inc. 1982). The water quality parameters in Table 6.21-2 are classified into five groups: common indicators, bacteria, nutrients, metals, and organics. These are basically the same parameters selected for the Connecticut River.

- Drinking Water Standards Both the National Interim Primary and Secondary Drinking Water regulations (U.S. EPA, 1979a) and the Massachusetts Drinking Water regulations (Massachusetts Division of Water Supply [MDWS], 1977) have been used as standards to evaluate the quality of the Millers and Tully Rivers and the treatment required to use the water for a public water supply.

  The National Interim Primary Drinking Water Regulations (U.S. EPA, 1979a) address the contamination of drinking water by metals, organics and radioactivity. They also include some commonly observed contaminants such as nitrate, fluoride, and turbidity. Massachusetts drinking water regulations conform to the Federal regulations in terms of the contaminants and the associated maximum levels. The drinking water standards generally apply to finished water at the tap but are used here for comparative purposes to evaluate suitability as a drinking water supply and water treatment requirements.

TABLE 6.21-1. SUMMARY OF DATA SOURCES AND EXTENT OF AVAILABLE DATA USED IN BASELINE WATER QUALITY DOCUMENTATION FOR THE MILLERS/TULLY RIVERS.

COLLECTING AGENCY/INSTITUTION	EXTENT OF AVAILABLE DATA	SAMPLING STATION*
Massachusetts Division of Water Pollution Control	Water quality surveys of physical and chemical parameters and bacteria levels during summer of 1965, 1973 and 1979	11 stations in the Millers/Tully River system
Army Corps of Engineers	Water quality sampling of physical and chemical parameters at the Tully Dam and Birch Hill Dam from 1977 to 1981. The periods of record at each station vary.	3 stations at the Tully Dam and Birch Hill Dam

*See Figure 6.21-1 for station locations.

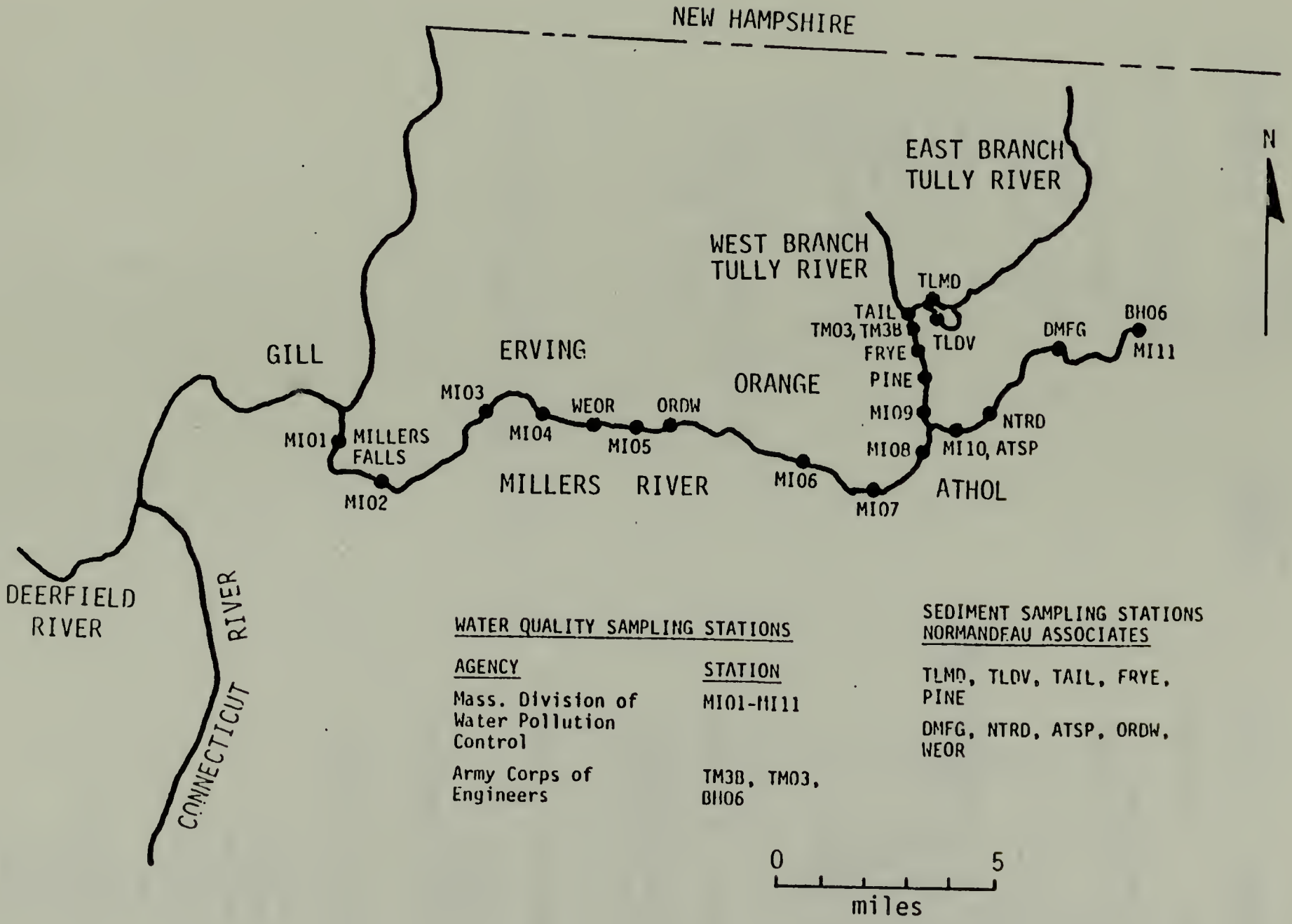


Figure 6.21-1. Water Quality Stations on the Millers and Tully Rivers sampled by previous investigators, and Sediment Stations sampled by NAI in 1982.

TABLE 6.21-2. WATER QUALITY PARAMETERS ANALYZED

PARAMETER	RATIONALE FOR CONSIDERATION* PUBLIC HEALTH	AQUATIC HABITAT	AESTHETICS
Group I - Indicators			
Temperature		x	
Dissolved Oxygen		x	
pH	x	x	x
Alkalinity		x	
BOD_5		x	
COD		x	
Total Dissolved Solids		x	x
Total Suspended Solids		x	x
Chloride	x	x	x
Fluoride	x		x
Sulfate		x	x
Turbidity	x	x	x
Color	x		x
Group II - Bacteria			
Total coliforms	x		
Fecal coliforms	x		
Group III - Nutrients			
Ammonia		x	
Nitrate	x	x	x
Total Phosphorus		x	x
Group IV - Metals			
Arsenic	x		
Barium	x		
Cadmium	x	x	
Chromium	x	x	
Copper	x	x	x
Iron		x	x
Lead	x	x	
Manganese			x
Mercury	x	x	
Nickel		x	
Selenium	x	x	
Silver	x	x	
Sodium	x		
Zinc		x	x

Continued

TABLE 6.21-2. (Continued)

PARAMETER	RATIONALE FOR CONSIDERATION* PUBLIC HEALTH	AQUATIC HABITAT	AESTHETICS
Group V - Organics			
Oil and grease		x	x
Phenols			x
Aldrin/Dieldrin	x	x	
Chlordane	x	x	
DDT	x	x	
Endosulfan	x	x	
Endrin	x	x	
Heptachlor	x	x	
Lindane	x	x	
Methoxychlor	x	x	
Mirex	x	x	
PCB	x	x	
Toxaphene	x	x	
2,4-Dichlorophenoxyacetic acid	x	x	
2,4,5-TP Silvex	x	x	

*New England Research, Inc., 1982a & b.

The second set of water quality standards of concern is the Massachusetts Water Quality Standards. In Massachusetts, general minimum water quality criteria have been developed for all surface waters in terms of aesthetics, radioactive substances, tainting substances, color, turbidity, total suspended solids, oil and grease, and nutrients (MDWPC, 1979). In addition, specific numerical criteria for dissolved oxygen, temperature, pH, and fecal coliforms have been established for various surface water classifications. The water quality standards for individual streams or portions of streams combine these criteria with water use designations.

The Millers River from mile point 35.7 to the confluence with the Connecticut River is classified as Class B waters and its use is designated as warm water fishery recreation.

- Existing water quality - Tables 6.21-3 and 6.21-4 present the range and mean recorded for each parameter at the proposed diversion in the Millers and Tully Rivers, using data from the (MDWPC) and Army Corps of Engineers (COE). The water quality data base does not indicate excessive levels of contaminants for many parameters. However, practically no data have been collected by state or federal agencies on organics (one oil and grease measurement) or on radioactivity, and existing data on metals for both rivers are limited. Tables 6.21-3 and 6.21-4 compare the existing water quality with maximum contaminant levels allowed in drinking water and ambient water quality standards for the two rivers. For the data sets available, turbidity and total coliform organisms consistently exceed the allowable levels (for drinking water quality) as would be expected for a raw water source. The pH mean for the Tully River is within the water quality standards even though some individual samples fell below the lower range limit. Trace metals are either present at very low levels or below the detection limits of the analytical methods used.

Considering downstream impact due to the diversion, the concentration profiles of some key water quality parameters in the Millers River are presented using the most recent data from MDWPC (Figure 6.21-2). These data were collected during two surveys in the summer of 1979. In general, water quality in the summer months is depressed due to the elevated temperature and reduced river flow as compared with other times of the year. The profiles in Figure 6.21-2 represent the worst conditions during the year. Also shown are the Massachusetts Water Quality standards for comparison

TABLE 6.21-3. MILLERS RIVER WATER QUALITY AT PROPOSED DIVERSION[a].

PARAMETER (DATA SOURCE)	UNITS	RANGE	MEAN	DRINKING WATER STANDARDS[b]	MASSACHUSETTS WATER QUALITY STANDARDS-CLASS B
GROUP I - INDICATORS					
Temperature (Summer)	°C	16.7-25.0	20.5		≤ 28.3
Dissolved oxygen	mg O_2/ℓ	5.7-10.7	8.2		≥ 5.0
pH	Std. units	7.0-7.2	7.1	6.5-8.5	6.5-8.0
Alkalinity	mg $CaCO_3$/ℓ	8-13	11		
BOD_5	mg/ℓ	1.8-2.7	2.1		
COD	mg/ℓ	No Data	--		
Total dissolved solids	mg/ℓ	90.5-119	100	500	
Total suspended solids	mg/ℓ	1.5-9.5	5.6		
Chloride	mg/ℓ	70-80	73	250	
Fluoride	mg/ℓ	No Data	--	1.4-2.4	
Sulfate	mg SO_4ℓ	3.0-6.3	4.1	250	
Turbidity	JTU	17-19	18	1	
GROUP II - BACTERIA					
Total coliforms	no./100 ml.	200-4500	1175	1	
Fecal coliforms	no./100 ml.	20-400	140		≤ 200
GROUP III - NUTRIENTS					
Ammonia	mg N/ℓ	0.02-0.22	0.12		
Nitrate	mg N/ℓ	0.4-0.5	0.5	10	
Phosphorus (total)	mg P/ℓ	0.13-0.34	0.25		

continued

TABLE 6.21-3. (Continued)

PARAMETER (DATA SOURCE)	UNITS	RANGE	MEAN	DRINKING WATER STANDARDS[b]	MASSACHUSETTS WATER QUALITY STANDARDS-CLASS B
GROUP IV - METALS					
Arsenic	µg/ℓ	<10	<10	50	
Barium		No Data	--	1000	
Cadmium	µg/ℓ	10	10	10	
Chromium	µg/ℓ	<10	<10	50	
Copper	µg/ℓ	10	10	1000	
Iron	mg/ℓ	0.85	0.85	0.3	
Lead	µg/ℓ	<10	<10	50	
Manganese	mg/ℓ	No Data	--	0.05	
Mercury	µg/ℓ	<0.1	<0.1	2	
Nickel(7)	µg/ℓ	50	50		
Selenium	µg/ℓ	No Data	--	10	
Silver	µg/ℓ	No Data	--	50	
Sodium	mg/ℓ	No Data	--	20	
Zinc	µg/ℓ	20	20	5000	
GROUP V - ORGANICS					
Oil and grease	mg/ℓ	1.0	1.0		

(a) MDWPC (1979), Station MI10, about 1.3 mi. downstream from proposed MDC diversion.

(b) Maximum contaminant level (MCL) for Primary or Secondary Federal Standards.

TABLE 6.21-4. TULLY RIVER WATER QUALITY AT PROPOSED DIVERSION.

PARAMETER (DATA SOURCE)	UNITS	RANGE	MEAN	DRINKING WATER STANDARDS[c]	MASSACHUSETTS WATER QUALITY STANDARDS-CLASS B
GROUP I - INDICATORS					
Temperature[a]	^{o}C	5.0-23.9	17.6		$\leq$ 28.3
Dissolved oxygen[a]	mg O_2/ℓ	6.3-10.4	7.91		$\geq$ 5.0
pH	Std. units	4.6- 7.0	6.0	6.5-8.5	6.5-8.0
Alkalinity[b]	mg $CaCO_3/\ell$	6-7	6.8		
BOD_5[b]	mg/ℓ	1.2-3.0	2.1		
COD	mg/ℓ	No Data	--		
Total dissolved solids[b]	mg/ℓ	40-73.5	52.3	500	
Total suspended solids[b]	mg/ℓ	3.5-10	6.8		
Chloride[b]	mg/ℓ	45-60	51.3	250	
Fluoride	mg/ℓ	No Data	--	1.4-2.4	
Sulfate	mg SO_4/ℓ	No Data	--	250	
Turbidity[a]	JTU	0.8-2.5	1.4	1	
GROUP II - BACTERIA					
Total coliforms[b]	no./100 ml.	200-700	385	1	
Fecal coliforms[b]	no./100 ml.	20-160	90		$\leq$ 200
GROUP III - NUTRIENTS					
Ammonia[a]	mg N/ℓ	<0.05-0.31	<0.13		
Nitrate[a]	mg N/ℓ	<0.02-0.05	<0.04	10	
Phosphorus (total)[a]	mg P/ℓ	<0.02-0.07	<0.035		

continued

TABLE 6.21-4. (Continued)

PARAMETER (DATA SOURCE)	UNITS	RANGE	MEAN	DRINKING WATER STANDARDS[c]	MASSACHUSETTS WATER QUALITY STANDARDS-CLASS B
GROUP IV - METALS					
Arsenic	µg/ℓ	No Data	--	50	
Barium	µg/ℓ	No Data	--	1000	
Cadmium[a]	µg/ℓ	<30-40	<35	10	
Chromium	µg/ℓ	No Data	--	50	
Copper[a]	µg/ℓ	<20-100	<60	1000	
Iron[a]	mg/ℓ	0.2	0.59	0.3	
Lead[a]	µg/ℓ	<20-30	<27	50	
Manganese[a]	mg/ℓ	<.05-.08	<.07	0.05	
Mercury[a]	µg/	<.1 - 2	<1.5	2	
Nickel	µg/ℓ	No Data	--		
Selenium	µg/ℓ	No Data	--	10	
Silver	µg/ℓ	No Data	--	50	
Sodium	mg/ℓ	No Data	--	20	
Zinc	µg/ℓ	<20-240	<100	5000	

[a]Range and mean based on Corps. of Engineers data for Station TM3B (discharge at Tully Dam), 1980-81.

[b]Range and mean based on MWPC data for Station MI-9 (near confluence with Millers River), 1979.

[c]Maximum contaminant level (MCL)

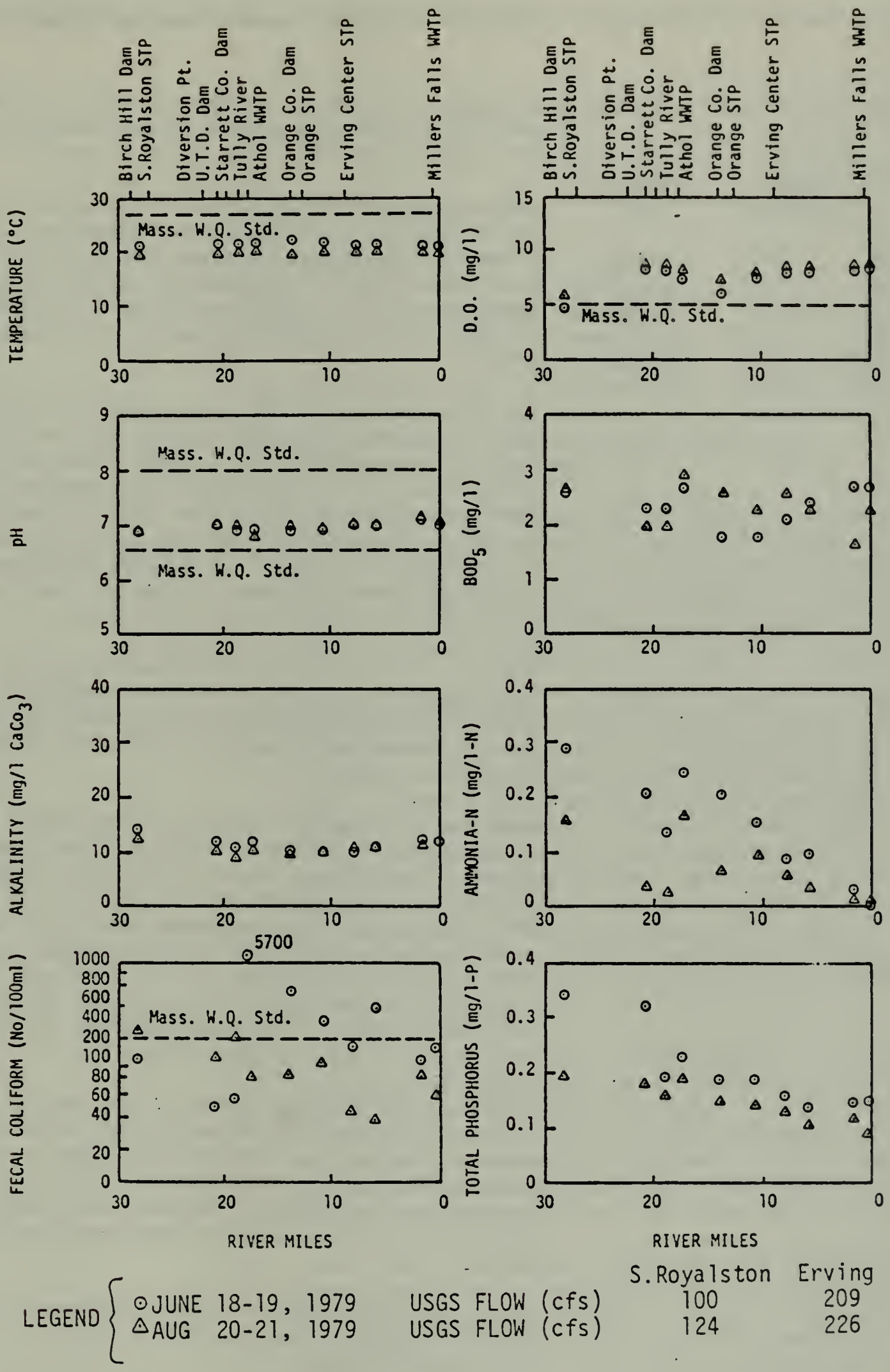


Figure 6.21-2 Millers River water quality, summer 1979

MDWPC,1979

purposes. The water quality in Millers River is generally good with more frequent violations of fecal coliform standards in the lower reaches.

Recent data on the Tully River watershed, particularly for Tully Lake, indicate that the waters of the east branch of the Tully River and Tully Lake continue to be of good quality and usually meet or exceed the requirements of their Massachusetts Class B designation. Areas of minor concern are occasional low pH levels.

The good quality of the east branch of the Tully River and its tributaries above Tully Lake in 1981 is shown in dissolved oxygen (DO) levels which are usually above 7 mg/l and always above the minimum required level as specified for Massachusetts Class B waters. Color levels in Tully Lake are high with measurements up to 150 pt-co units. This high color level is due to marshy areas upstream of the lake and has been observed over a long period of time.

The pH levels in Tully Lake are relatively low with a measured mean of 5.9 and an observed range from 4.3 to 7.0. The low pH levels in Tully Lake are most likely due to natural degradation of material from the upstream marshes.

Nutrient analyses of the Tully Lake water indicate relatively low nitrogen levels. Total inorganic nitrogen levels are about 0.1 mg N/l. Total phosphorus levels are between 0.02 to 0.05 mg P/l. Tully Lake has a hydraulic residence time of 2 to 3 weeks under normal summer flow conditions and approaches stagnation under minimum flow conditions. There are no significant algae growth problems during the summer low flow months. Eutrophication has not been a noticeable problem in Tully Lake.

Metal levels in Tully Lake are low except for zinc. However, there is no evidence that these zinc levels are causing problems for aquatic life, and the concentrations are far below the 5000 ug/l MCL for drinking water quality. Mercury and copper levels in Tully Lake have been low or below the detection limits.

- Wastewater Discharges - Major municipal wastewater discharges in the Millers River within the study area are listed in Table 6.21-5.

Table 6.21-5. MAJOR MUNICIPAL WASTEWATER DISCHARGES*

Facility	River Mile	Treatment Level	NPDES Permit Limit. Flow(mgd)	BOD
S. Royalston	27.6	secondary	0.03	30 mg/1
Athol	18.7	secondary	2.25	30 mg/1
Orange	13.3	secondary	1.1	30 mg/1
Erving	9.0	secondary	3.15	900 lb/day
		primary	3.15	1700 lb/day**
Millers falls	0.2	secondary	1.02	255 lb/day

* Franklin County Planning Commission, 1979
** When temperature below 15°C.

Major sources of industrial discharges are treated in joint municipal/industrial treatment plants at Erving and Millers Falls Sewage Treatment Plants (STPs). Smaller amounts of industrial wastewater from Starrett Company in Athol are treated before being discharged into the Millers River.

- Sediment Chemistry - Contaminants reaching water bodies such as rivers and lakes may often become incorporated into suspended and bottom sediments (see for example: Riemer and Toth, 1970; Shuman et al., 1978). These contaminants can subsequently be released (remobilized) to the overlying waters or redistributed via several chemical-physical mechanisms including: particle transport associated with bed scouring during flood flows, desorption from organic and inorganic particle surfaces, dissolution of mineral particles and oxide coatings, and direct incorporation into biological tissue (see: Ramamoorthy and Rust, 1978).

Sediment samples in the Tully and Millers River systems were collected in the summer of 1982 at the locations shown in Figure 6.21-1. The locations were selected to assess the potential influence of bottom contaminants on water to be diverted and on downstream water quality and aquatic life. The results of the analyses are presented in the Water Quality Appendix.

These results indicate relatively low levels of heavy metals and PCBs in the sediments of the Millers and Tully rivers. The sediments are not considered contaminated based on these data because their concentrations are several orders of magnitude lower than those measured in dredged materials from waterways across the nation. An examination of these results suggests that the river sediments would not be

an important source of heavy metals and PCBs to the overlying water, and the metal and organics levels in Millers and Tully Rivers are not expected to increase significantly in the near future.

II. Future Conditions Without Alternative - This section describes the future water quality conditions in the Millers River and Tully River if diversion does not occur. The water quality conditions are assessed for three time periods, 1990, 2000, and 2020.

The assessment is based on the limited data on future changes in land use and population in the watershed which effects changes in the background water quality in the Millers and Tully Rivers. Due to the limited data on future land use and population in the watersheds, the analysis is rather qualitative.

Table 6.21-6 shows the predicted population for different towns in the drainage basin for the years 1980, 1990, and 2000. The predicted population for the year 2020 is not available. (Franklin County Planning Commission, 1979)

Table 6.21-6. POPULATION IN YEARS 1980, 1990, AND 2000 FOR TOWNS IN THE MILLERS AND TULLY RIVER WATERSHEDS

TOWN	1980	1990	2000
Athol[a]	10,643	11,151	11,289
Erving[b]	1,325	1,360	1,375
Orange[b]	6,585	6,820	6,915
Phillipston[b]	1,005	1,126	1,247

[a] Task 1: Water Demand Projections Interim Technical Report, January 1983.
[b] Franklin County Planning Commission, 1979.

Table 6.21-6 shows that population in the watershed is not expected to increase significantly from a water quality perspective over the next two decades. In relating the population increase to potential changes in stream water quality, the point source discharges from municipal wastewater treatment plants and a number of municipal dischargers within the watershed have been considered. (See Table 6.21-5.) No major problems have been reported at these facilities. Many of the wastewater treatment plants are not operating to the design flow capacity although occasionally the BOD effluent limitations are exceeded. In terms of the total allowable BOD loading limits in pounds per day, the facilities are discharging less than the effluent limit. Based on the small increase in population and sufficient reserved capacity at

wastewater treatment plants we do not expect any significant increase in permitted wastewater pollutant loadings through the year 2000.

The industrial point sources are also not expected to substantially increase in the years 1990 and 2000. Manufacturing employment in four of the towns in the drainage basin (for which employment projections are available) is expected to increase by approximately ten (10) percent by 2000. Concurrently, regulatory requirements to improve (reduce) effluent loadings will be implemented. The resultant net effect of future industrial discharge is expected to be less than the existing discharges. Therefore, we do not expect significant water quality degradation due to point source discharges in the Millers River in the years to come.

As the influence of point sources of municipal and industrial wastewater discharges begin to diminish due to increased treatment, the effects of the more diffuse urban and non-urban sources become more apparent. Studies over the past decade have begun to produce a substantial data base on various types of distributed inputs from urban, agricultural and undisturbed land areas.

Two of the most important sources of nonpoint pollution are urban development and agricultural activities. A wide variety of land runoff models are presently available to evaluate the magnitude of runoff discharges from urban areas served by combined sewerage and separate sewerage systems. Factors influencing runoff yields from agriculture areas include rainfall characteristics, soil type, ground slope, ground cover, soil management practices and fertilization. Typical exports of nutrients from forested areas of different underlying geological formations can be found in the literature. These typical concentrations of BOD, nutrients, coliform bacteria and sediment may be useful in quantifying nonpoint source loadings from the watershed. However the projected long term changes in land uses for the three specific time periods are currently not available. Employment in agriculture in the four towns in the study area is expected to be reduced by fifty percent by the year 2000. Although agricultural contributions are expected to be less, a detailed quantification of nonpoint source loading changes on a long-term basis cannot be made. Based on the perspective that limited growth is expected to occur in the next decades and that agricultural activities will decline, it is reasonable to believe that any water quality changes due to nonpoint pollution increase would be so small that they may not be differentiable from the year-to-year variations of natural background water quality. Due to the relatively insignificant increases in point source and

nonpoint source loadings to the Millers River in the next few decades, the river water quality is not expected to undergo any appreciable changes through the year 2000.

The relatively small watershed of Tully Lake is not expected to be significantly developed during the next few decades. There is no major point source discharge of wastewater into the lake at the present time and the watershed is not expected to receive significant point source discharges in the years to come. Because of the limited development projected for the Tully lake watershed, increases in loadings of nonpoint source pollutants are not expected.

6.21.2 Future Conditions With Alternative

In developing a simplified approach for water quality impact assessments, we have considered the following factors:

- flows in the Millers and Tully Rivers;
- time scale of water quality problem; and
- chemical, bio-chemical, physical and biological variables of importance

The most direct impact of the diversion is on the river flow which in turn has a significant bearing on the water quality downstream from the diversion point. Transfer of the water from Millers and Tully Rivers is allowed when the flows are in excess of the following discharges (Table 6.21-7):

Table 6.21-7. MINIMUM FLOW REQUIREMENTS FOR MILLERS AND TULLY RIVERS[a]

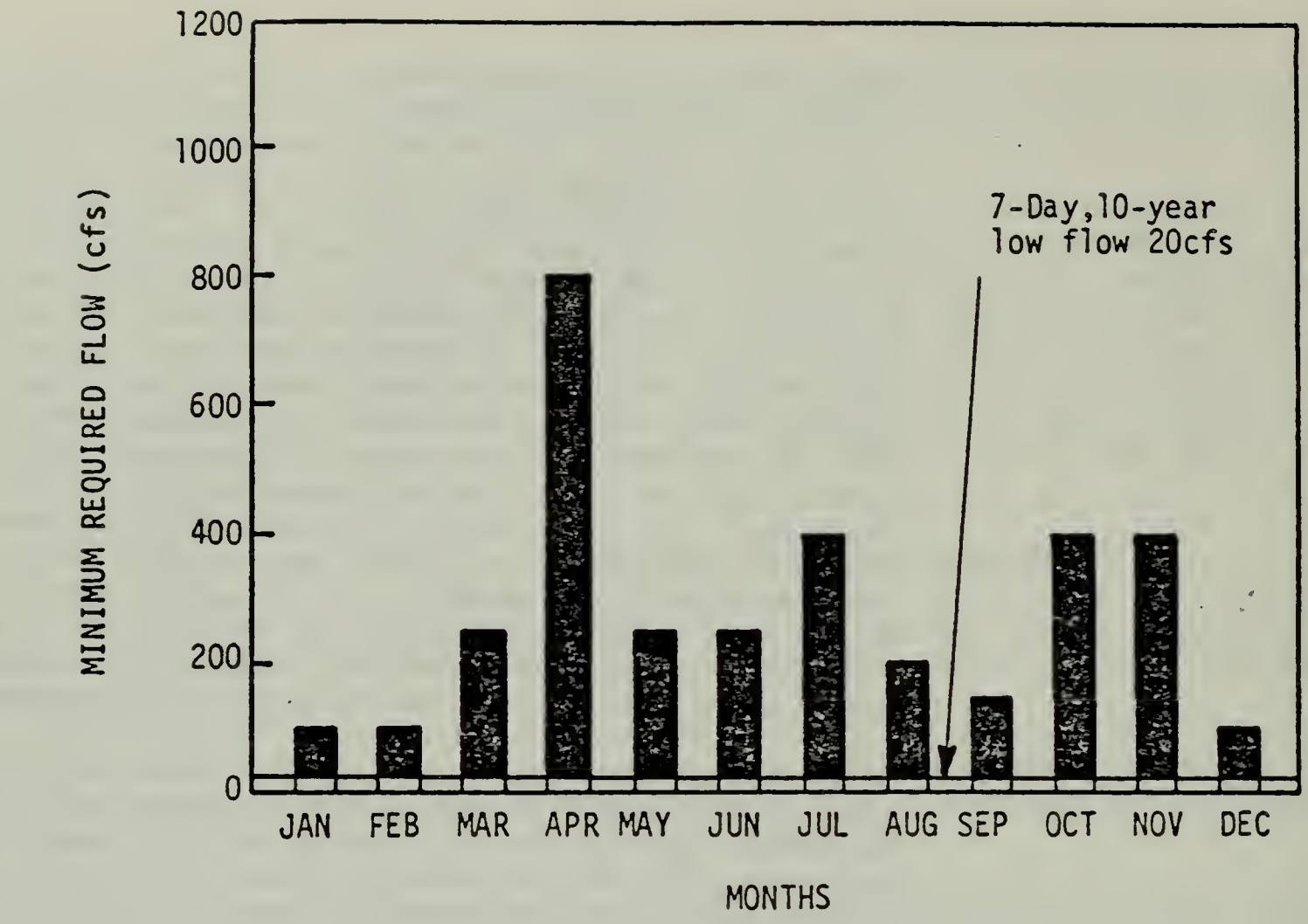
Month	Minimum Flow			
	Millers River (Athol)		East Branch Tully River	
	Flow (cfs)		Flow (cfs)	
	Minimum	Average	Minimum	Average
Jan	100	323	25	76
Feb	100	315	25	74
Mar	250	569	63	150
Apr	800	833	200	222
May	250	449	63	112
Jun	250	254	63	60
Jul	400	128	100	28
Aug	200	103	50	20
Sep	150	121	38	28
Oct	400	180	100	34
Nov	400	267	100	60
Dec	100	316	25	77

[a] US Fish and Wildlife Service constraints for maintenance of aquatic life.

The minimum flow requirements (at Athol) are also shown in Figure 6.21-3 along with the 7-day 10-year low flow at South Royalston. (The drainage area at Athol is 200 sq. mi. and the drainage area at South Royalston is 187 sq. mi.). As seen from Figure 6.21-3, the 7-day 10-year low flow at South Royalston is far below the minimum flows required at Athol. Also shown in Figure 6.21-3 is the percent of time the flow at Athol (derived from the flow at South Royalston based on drainage basin area ratio) is greater than or equal to the minimum required flow on a monthly basis. During the first five months, the flows at Athol are generally greater than the required flows more than 50% of the time. In the summer months (June to September), the flows usually decrease and the percent of time that the flows are greater than or equal to the required flows drops sharply. It is during these summer months when temperature reaches its annual peak, that the water quality conditions are under significant stress and are of major concern from the standpoint of diversion.

It is useful to associate the low flow characteristics as shown in Figure 6.21-3 with a given flow pattern during a particular year so that the year(s) may be viewed as a worst case year in the impact analysis. Our first step to achieve this is to compare the characteristics of required flow with the daily flows of the Millers River at Athol on a month by month basis for the past 50 years. Table 6.21-8 shows the lowest percent of time which flows were greater than or equal to the minimum required flow in each month. For example, daily flows were greater than or equal to 100 cfs only 6.5 percent of the time in January 1944. This percentage is the lowest throughout the period of record for January. Also, in many years, the summer and fall months have no daily flows greater than the minimum required flow, indicating the required flows are relatively high compared to the available flow.

On a whole year basis, it is difficult to find a year in the past which had the flow characteristics identical to the low flow characteristics shown in Figure 6.21-3. Some of the relatively close matches are identified and presented in Table 6.21-9. In general, the drought period from 1948 to 1950 can be considered having flow patterns similar to the one associated with the required low flows. In addition, the flow patterns in 1963, 1964, and 1971 had low flow characteristics which resemble the pattern of required low flows. The summer low flow characteristics in these selected six years all have flows frequently below the required low flows in the summer and fall months (June to November). Therefore, use of these years as worst case years in an impact assessment should give more conservative results than the required low flows during the summer and fall months. Table 6.21-10 shows the lowest percent of time



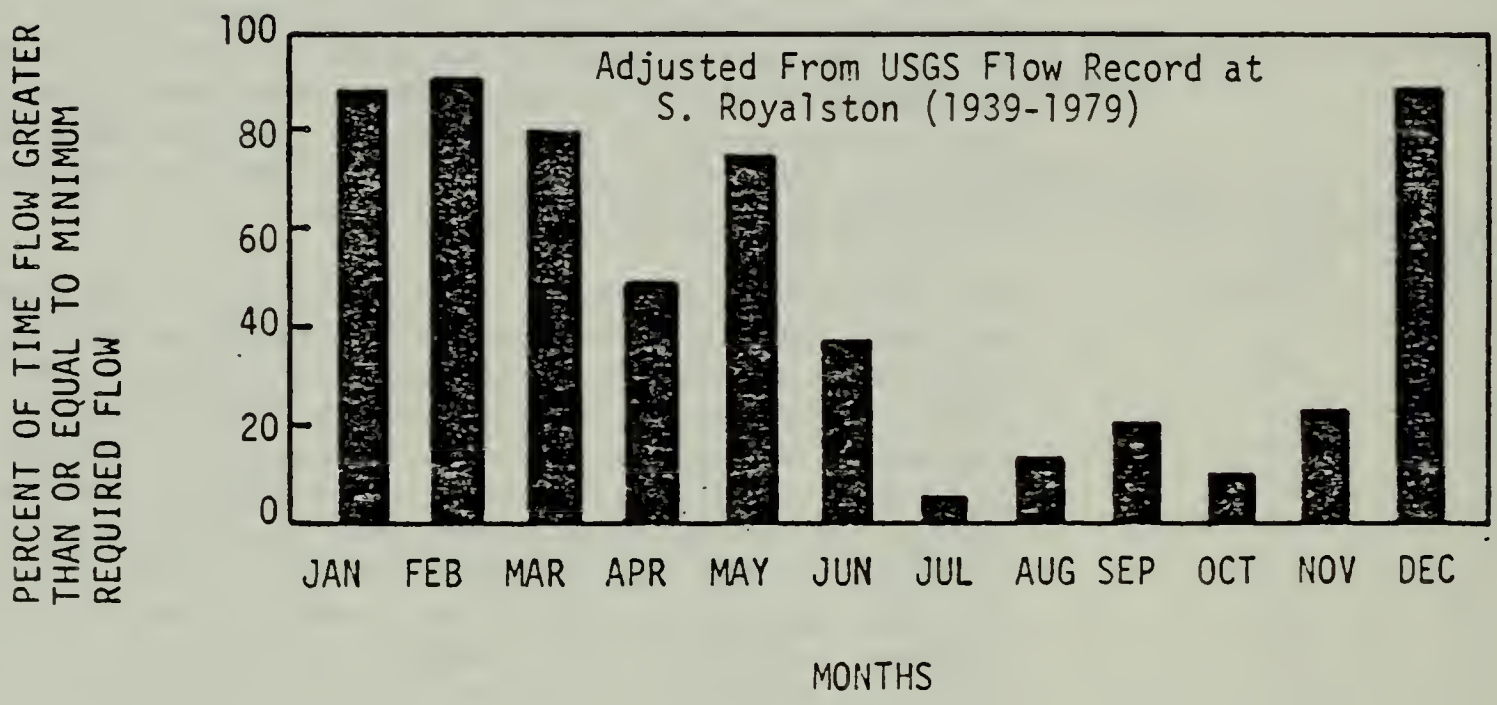


Figure 6.21-3 Millers River low flow requirements and low flow durations at Athol.

TABLE 6.21-8. MILLERS RIVER FLOW, HISTORIC WORST CASE MONTHS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Minimum Required Flow (cfs)	100	100	250	800	250	250	400	200	150	400	400	100
Lowest Percent Occurrence of Time Greater Than or Equal to Minimum Flows	6.5	14.3	9.7	0.0	6.5	0.0	0.0	0.0	0.0	0.0	0.0	19.4
Year(s) when lowest percentage was attained	1944	1977	1965	1941 1942 1946 1965 1966	1965	1941 1949 1957 1958 1963 1964 1965 1966	1940-43 1947 1949 1950 1952 1953 1955-58 1961-66 1970 1971 1974 1977 1978 1979	1940 1941 1944 1947 1948 1949 1950 1953 1956 1959 1963 1966 1968 1970 1974	1939 1940 1947 1949 1953 1957 1962 1964 1965 1968 1976 1978	1939 1942 1944 1945 1947 1950 1952 1954 1956 1957 1961 1963 1972 1976 1978	1941 1944 1946 1949 1952 1957 1964 1965 1970 1971 1976 1978	1964
Total for years of record	1	1	1	5	1	8	14	15	12	15	12	1

TABLE 6.21-9. PERCENT OCCURRENCE OF FLOWS IN MILLERS RIVER GREATER THAN OR EQUAL TO MINIMUM REQUIRED FLOWS AT ATHOL, MA.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1948	80.6	65.5	80.6	40.0	93.6	100.0	12.9	0.0	0.0	0.0	12.3	77.4
1949	96.9	100.0	100.0	10.0	64.5	0.0	0.0	0.0	0.0	0.0	0.0	71.4
1950	100.0	100.0	58.1	40.0	35.5	33.3	0.0	0.0	10.0	0.0	16.7	100.0
1963	100.0	100.0	64.5	50.0	51.6	0.0	0.0	0.0	3.3	0.0	20.0	100.0
1964	100.0	100.0	87.1	43.3	22.6	0.0	0.0	0.0	0.0	0.0	0.0	19.4
1971	83.9	96.4	93.5	76.7	83.9	3.3	0.0	12.9	20.0	0.0	0.0	100.0
Combined years 1939-1979	85.8	90.9	79.4	47.8	75.2	36.4	4.9	12.7	20.2	9.4	24.1	88.5

[a]For years when at least 3 month(s) had no flow above the minimum requirement

TABLE 6.21-10. TULLY RIVER FLOW, HISTORIC WORST CASE MONTHS.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Minimum Required Flow (cfs)	25	25	63	200	63	63	100	50	38	100	100	50
Least Percent Occurrence of Flows Greater Than or Equal to Minimum Flows	0.0	0.0	16.1	0.0	9.7	0.0	0.0	0.0	0.0	0.0	0.0	
Year(s) When Least Percentage was obtained	1965	1940 1965		1930 1942 1946	1930	1932 1933 1939 1941 1949 1958 1963 1966 1971	1931 1934 1936 1939 1943 1947 1949 1950 1952 1966 1970 1971 1974 1976 1979	1930 1932 1934 1936 1939 1940 1944 1947 1950 1953 1954 1956 1959 1961 1968 1974 1977 1978	1930 1931 1936 1939 1940 1942 1944 1946 1949 1950 1953 1957 1958 1961 1966 1968 1972 1973 1976 1978	1929 1931 1935 1939 1942 1944 1950 1952 1954 1956 1958 1961 1963 1971 1973 1978	1929 1931 1941 1944 1946 1949 1952 1956 1958 1961 1963 1965 1967 1970 1971 1976 1978	1964
Total for years of record	1	1	1	3	1	9	15	17	19	16	17	1

which flows were greater than or equal to the minimum required flow in each month for the Tully River. Table 6.21-10 also indicates that the least amount of time flows reach the required threshold during the months from June to December is zero in many years, indicating the required flows are relatively high compared to the available flow.

As with the Millers River, there has not been a year in which East Branch Tully River flow characteristics identical to the low flow characteristics as shown in Figure 6.21-4 has occurred. Some of the relatively close matches are identified and presented in Table 6.21-11. In general, the years 1930, 1936, 1942, 1947, 1962, and 1972 had the low flow characteristics on a monthly basis which resemble the pattern of required low flows for East Branch of the Tully River.

It is necessary to select a flow for water quality impact assessment. Although the 7-day 10-year low flow is commonly used in Massachusetts for waste load allocation and water quality modeling purpose, it is inappropriate for this analysis. First, the monthly minimum flows are all above the 7-day 10-year low flow (Figure 6.21-3). Therefore, there will be no impact during low flows because no diversion will take place when the river flow is below the minimum flow. Thus, it would be more reasonable to assess the water quality impact based on the monthly minimum flows. Because the minimum flow required to maintain the river ecosystem varies from month to month, it would be necessary to assess the impact on an individual month basis. This rationale is better justified when considering nonconservative substances whose kinetics are temperature dependent from season to season (i.e. dissolved oxygen).

The next consideration is the time and space scales. For the Millers River, historic data[a] on the time-of-travel indicate that it takes about 1 to 3 days for a parcel of water to travel from the proposed diversion point to the mouth of the river (Figure 6.21-5). Diversion of water is expected to reduce the flow and thereby increase the time-of-travel slightly. The effect of diversion on the river flow is estimated to be sustained over the entire section of the river from the diversion point to the mouth (over 20 miles) based on an average annual transfer rate of 70 cfs (considering maintenance of a flow of 17,000 cfs in the Connecticut River at the Montague Dam). Thus, we are dealing with a time scale in days and a space scale of 10 to 20 miles when assessing the water quality impacts.

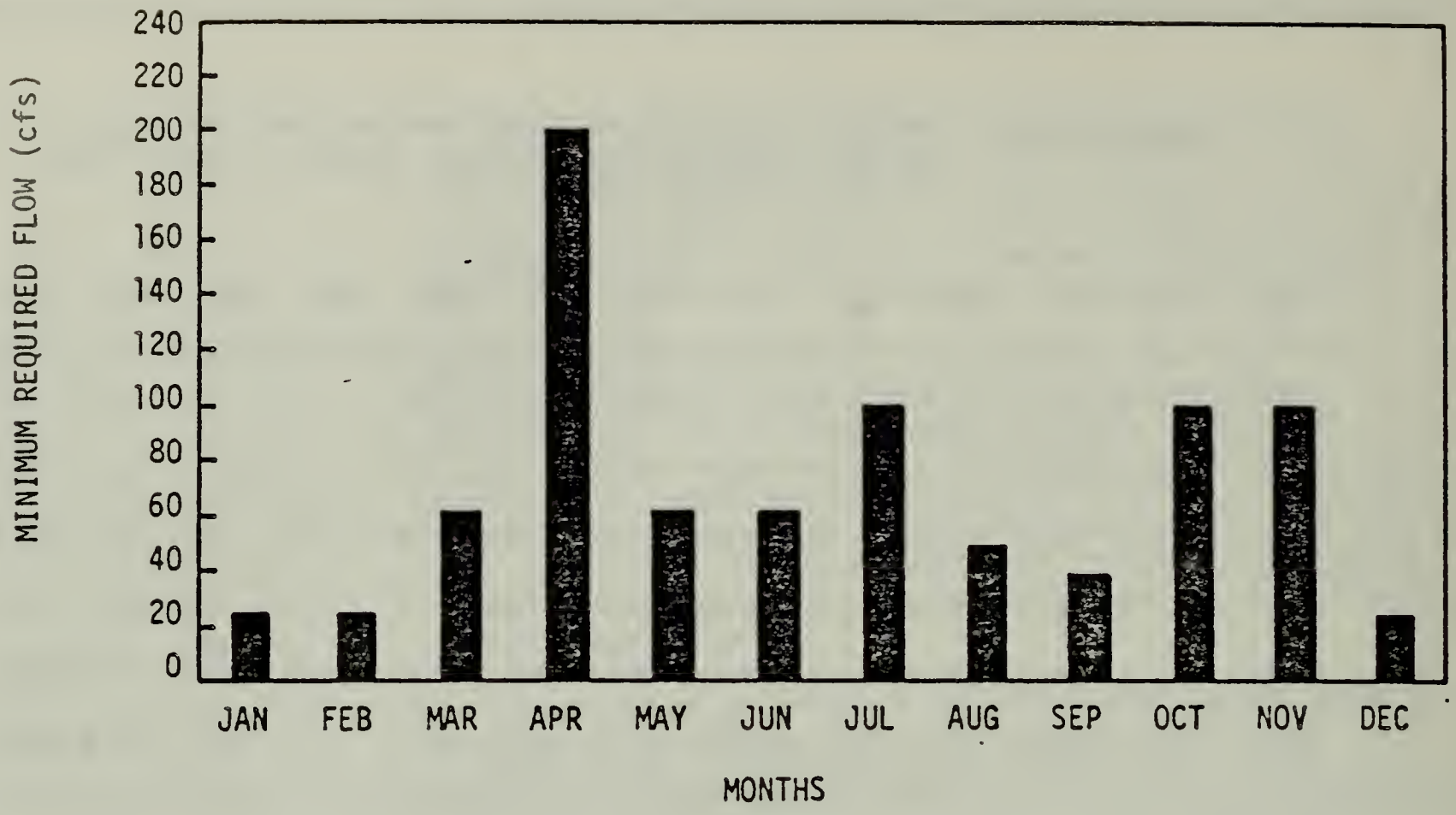
---

[a]U.S. Geological Survey and Massachusetts Division of Water Pollution Control

TABLE 6.21-11. PERCENT OCCURRENCE OF FLOWS GREATER THAN OR EQUAL TO MINIMUM REQUIRED FLOWS IN EAST BRANCH OF TULLY RIVER.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1930	67.7	53.6	87.1	0	9.7	10.0	6.5	0	0	0	0	38.7
1936	93.5	100.0	67.7	56.7	41.9	3.3	0	0	0	3.2	3.3	90.3
1942	83.9	96.4	74.2	0	22.6	33.3	0	6.5	0	0	23.3	100.0
1947	51.6	100.0	58.1	60.0	96.8	50.0	0	0	0	0	20.0	74.2
1962	77.4	50.0	51.6	56.7	80.6	3.3	0	0	0	16.1	3.3	100.0
1972	100.0	100.0	83.9	56.7	80.6	63.3	9.7	9.7	0	9.7	13.3	100.0
Combined Years 1929-1979	79.9	87.0	72.2	46.9	68.8	31.7	5.5	8.3	14.6	8.1	17.7	80.8

[a]For years when at least one month had no flows above the minimum requirement



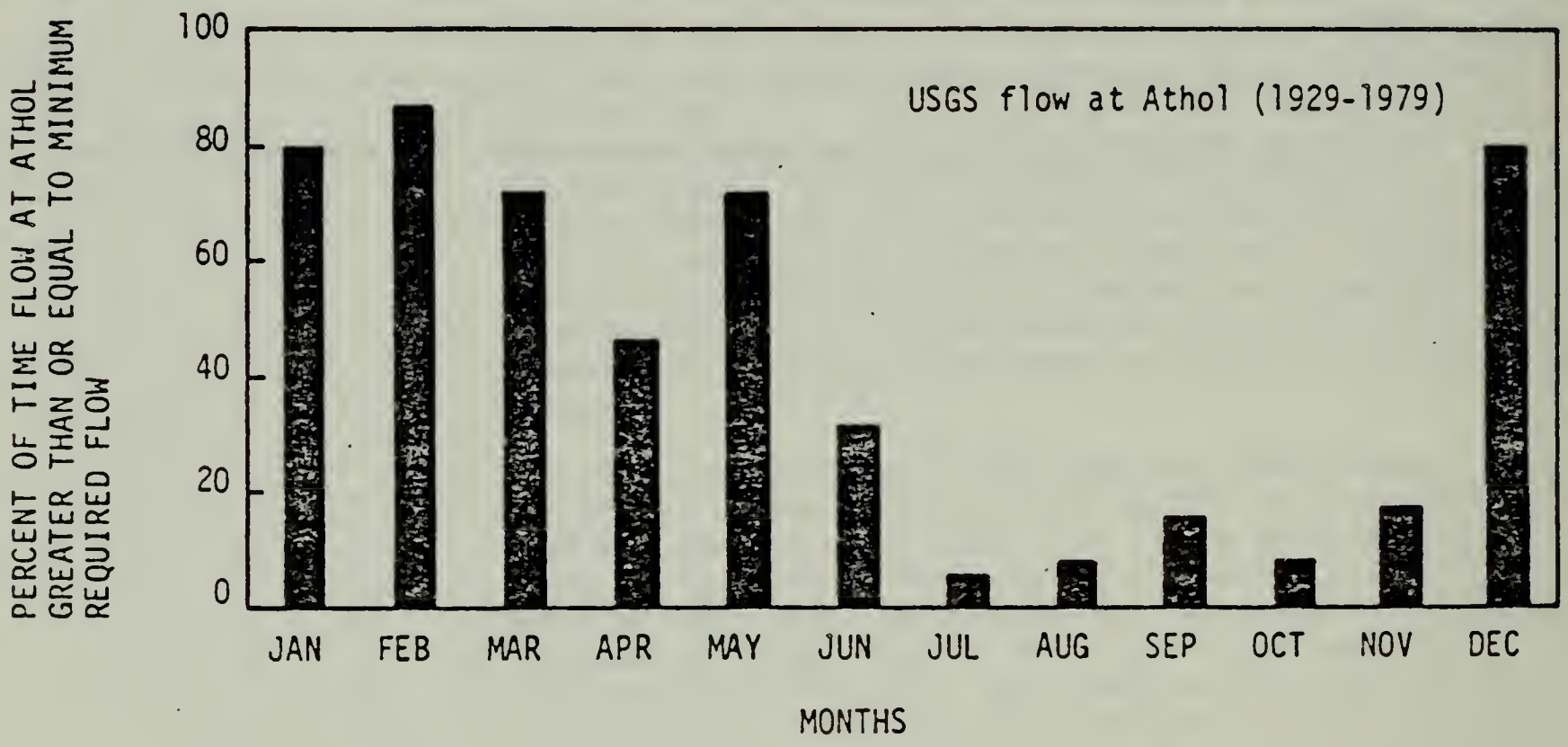
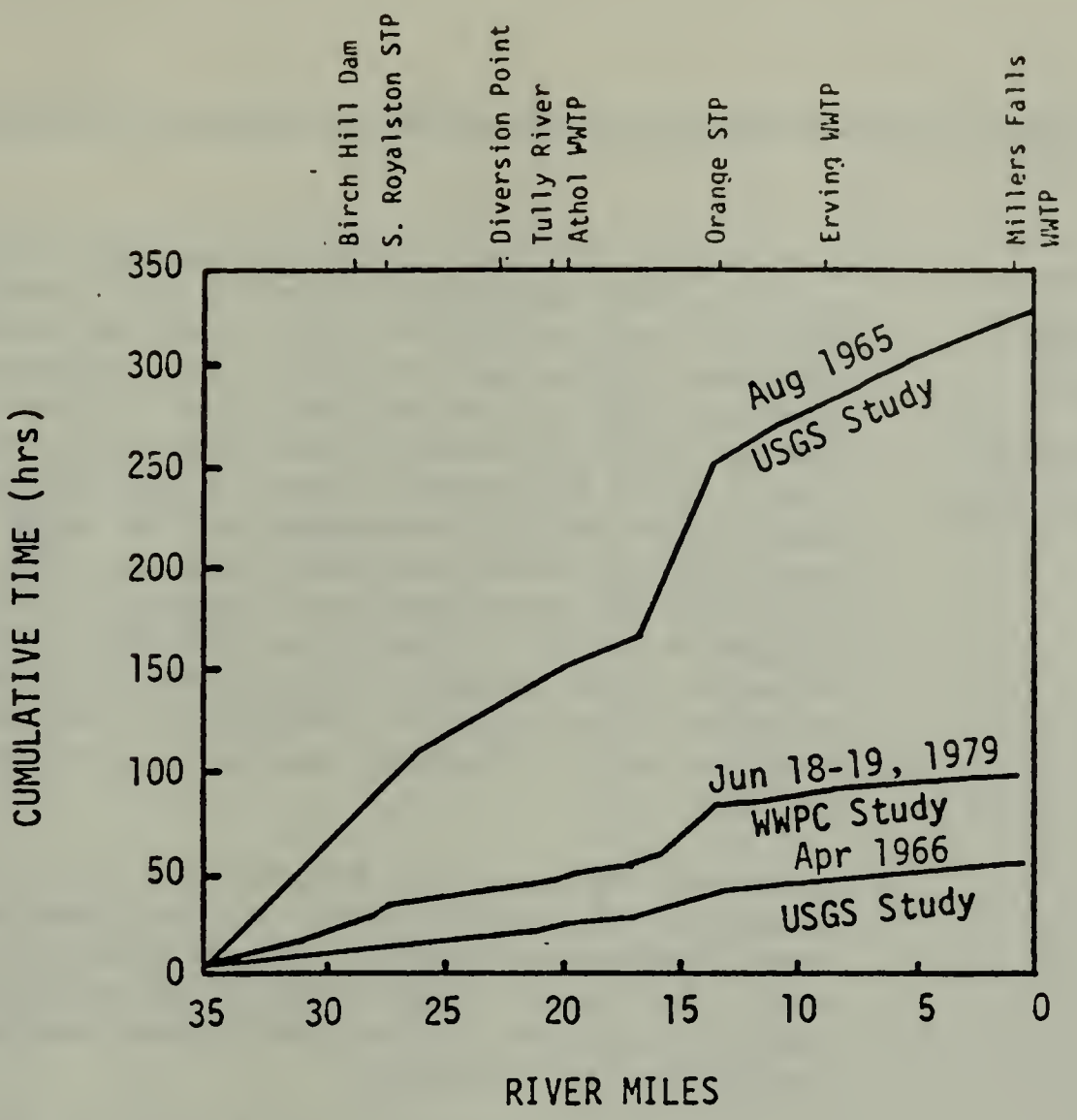


Figure 6.21-4. Tully River low flow requirements and low flow duration at Athol.



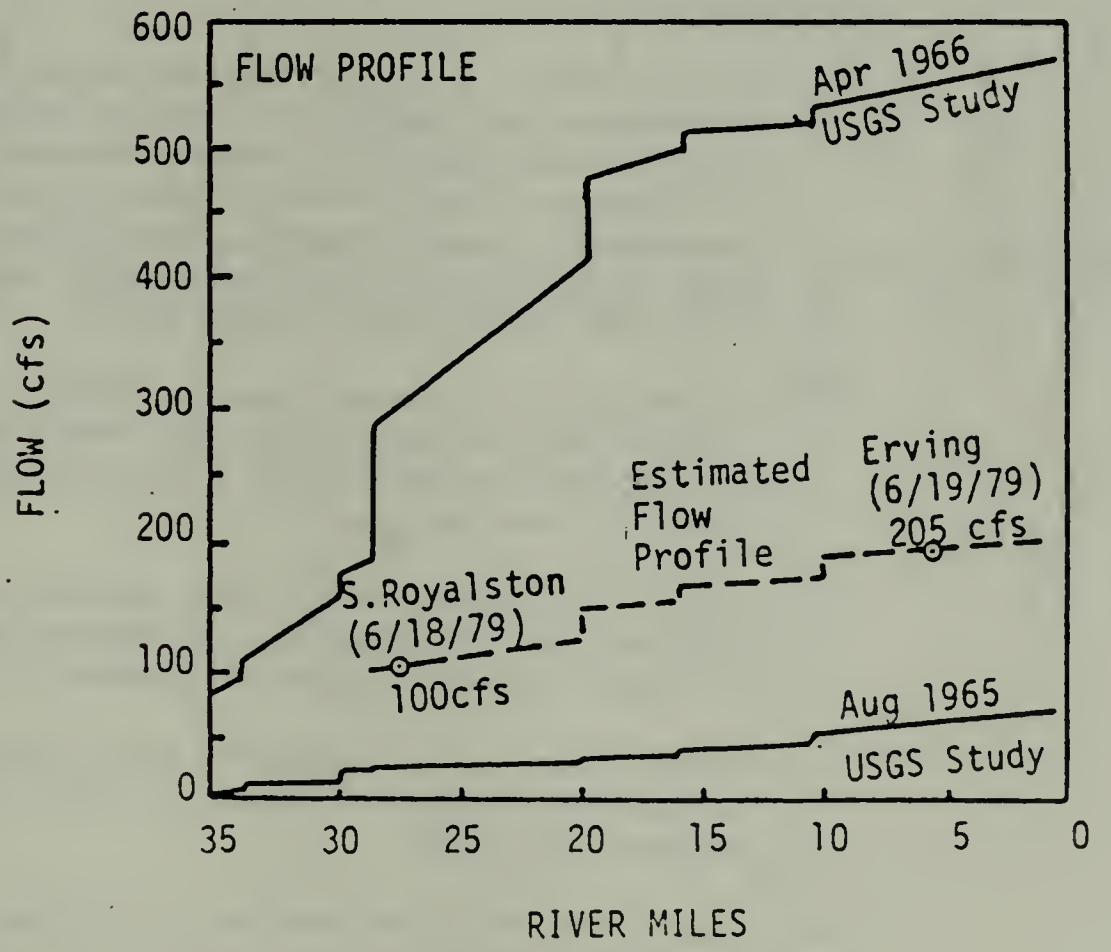


Figure 6.21-5. Time of Travel and Flow Profiles in Millers River. Source: U.S. Geological Survey (1969) and Massachusetts Division of Water Pollution Control (1980).

Examination of Figure 5.21-5 in Section 5.21.2 suggests that the most significant water quality problems on the Millers River within the above time and space scales are dissolved oxygen and bacteria. This judgement is also substantiated for the Millers River by the predominance of BOD and bacteria loadings from the wastewater treatment plants along the study section of the Millers relative to other water quality constituents. In addition, these two water quality parameters have been the major concern in the Millers River under existing conditions (Figure 6.21-2 in Section 6.21.1.I). Therefore, the impacts on these two parameters are addressed by evaluating the reduction capacity of the river to assimilate dissolved oxygen and bacteria due to diversion and the associated flow reduction.

To assess the impact of diversion on the dissolved oxygen levels in the Millers River, a simplified methodology (one-dimensional dissolved oxygen modeling framework) was used. The use of such a simplified methodology is justified in view of the limited data available and constraints of the study.

A detailed description of the simplified methodology is presented in the Water Quality Appendix. A few key assumptions and their justifications for the modeling calculations are:

1. Steady-state, i.e., all stream water quality parameters and inputs are assumed constant in time. Steady-state dissolved oxygen balance is considered as the first-cut analysis for water quality impact assessment. The temporal characteristics associated with diversion as described earlier are consistent with the steady-state assumptions.

2. Subsequently, constant spatial system parameters, e.g. river flow, deoxygenation and reaeration coefficients, are assumed constant with distance along the flow axis of each river section.

3. Only point source waste load inputs are included. This is justified because the majority of BOD loadings are from the 4 municipal wastewater treatment plants.

4. Uncertainty in the analysis of various constituents is incorporated to some degree in the "background" or natural quality.

Once the calculation methodology is defined, the next step is to develop a strategy for making the calculations. Figure 6.21-6 shows the maximum, mean, and minimum flows for each month of the water year 1980.

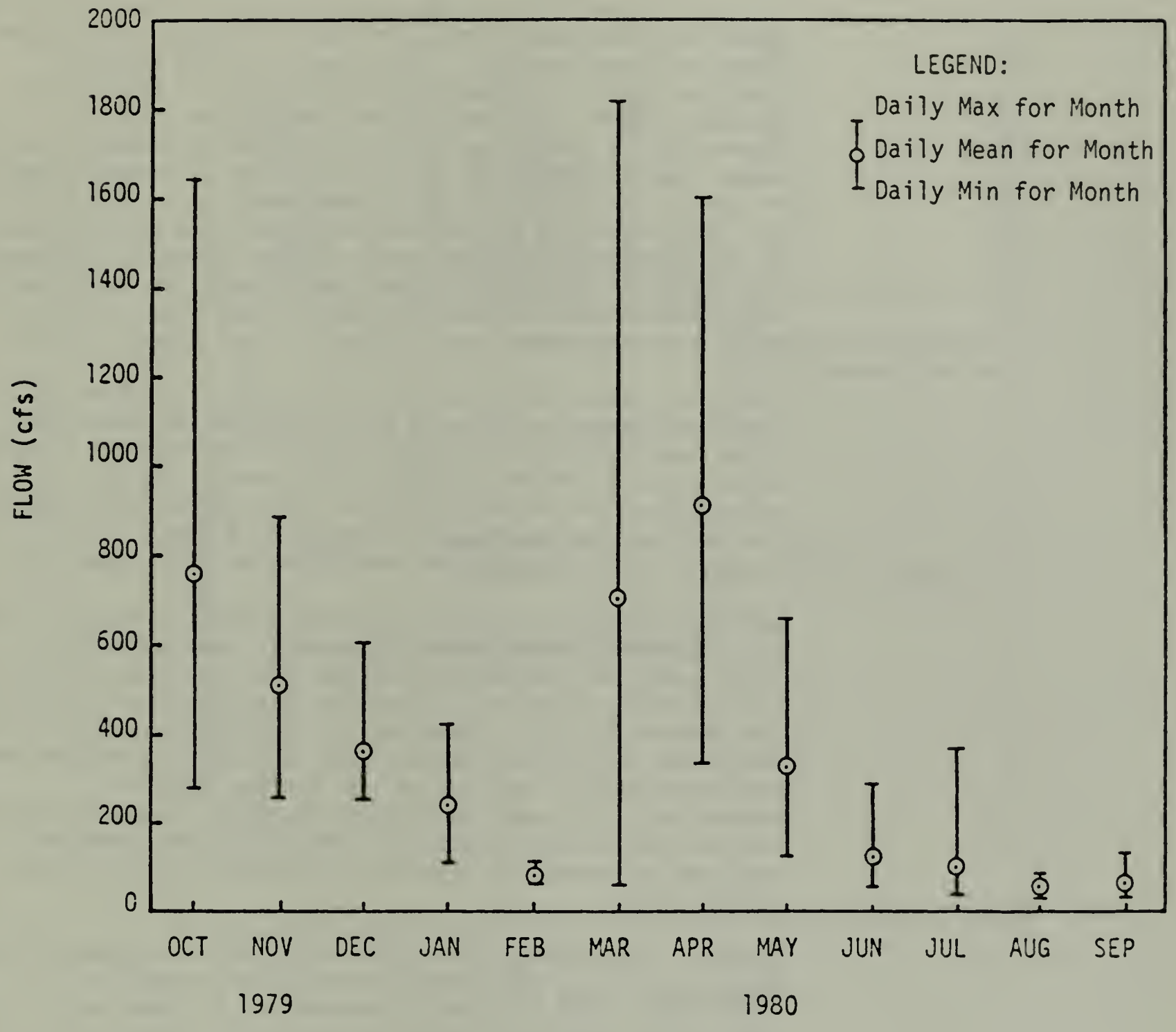


Figure 6.21-6. Monthly Millers River flow at S. Royalston (USGS, 1981).

Usually, minimum flows consistently occur in the months of August and September (note the maximum, mean, and minimum flows for other months). Therefore, a worst monthly condition would be expected in the months of August and September with a maximum stream temperature of 30°C. Figure 6.21-3 indicates that the minimum allowable flows in August and September are 200 cfs and 150 cfs respectively at Athol. Therefore, a worst case condition would be 150 cfs (the lesser of August and September) and a temperature at 30°C (higher than historical records indicate for these two months). Even this "worst case" condition could occur only approximately 20 percent of the time since diversion would not be allowed more frequently (see Figure 6.21-3).

The above calculation procedure was used to analyze the dissolved oxygen profile in the Millers River under the worst case condition of reducing the river flow at Athol to 150 cfs due to water transfer. The results of the calculations are shown in Figure 6.21-7 (detailed results can be found in Water Quality Appendix Section 6.21.2.). As Figure 6.21-7 indicates, the model predicts that the

minimum dissolved oxygen in the Millers River will be above the standard (5 mg/l) under this worst case condition. This result is consistent with the observed data in June 1979 when the flow at S. Royalston reached about 100 cfs (see Figure 6.21-5). That is, the flow reduction due to diversion is not expected to cause a dissolved oxygen water quality violation as long as the minimum flow is maintained. Although the dissolved oxygen concentrations may be less during periods of low flows (less than the required minimum), no diversion is planned during those occurrences.

Because the minimum flows in other months are always higher than 150 cfs and the stream temperature is equal to or lower than 30°C., any other combination of flow and temperature would not produce a dissolved oxygen condition worse than that represented by Figure 6.21-7. Thus, the flow reduction due to diversion would not result in water quality violations for dissolved oxygen.

Other water quality parameters potentially impacted by the diversion may be conservative substances (e.g. suspended solids) or bacteria concentrations. The data base for bacteria is not sufficient to perform an analysis similar to the one for dissolved oxygen. The principal difficulty is the lack of information on coliform bacteria decay rates in the Millers River. Literature data indicate a wide variation in the rate of bacterial decay. Thus, it would be desirable to derive a site-specific decay rate for the Millers River in future studies. Nevertheless, under low flow with flow diversion conditions, the coliform bacteria

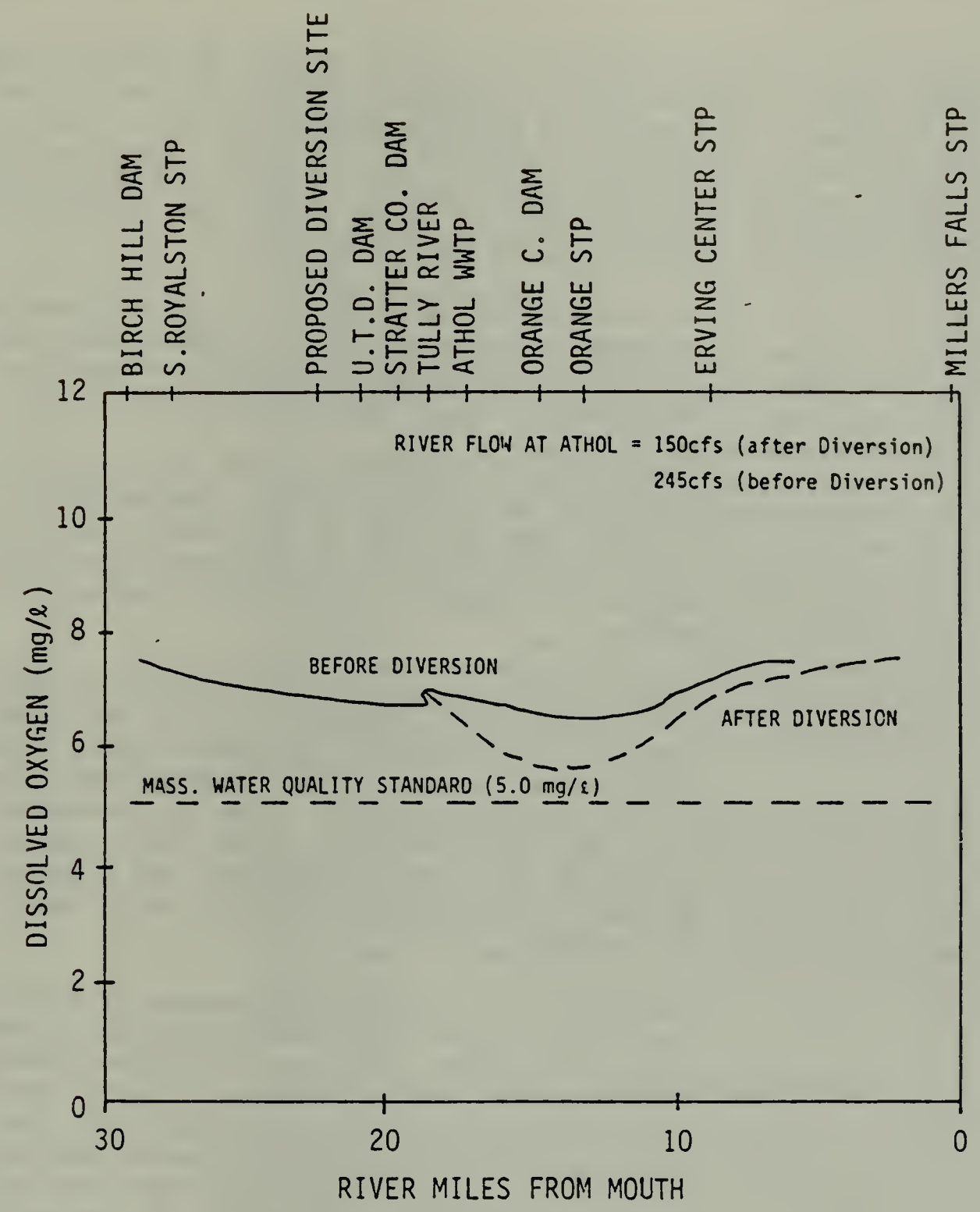


Figure 6.21-7. Calculated dissolved oxygen profiles in The Millers River.

should die-off rapidly because of the warm temperatures and therefore, its impact would be limited to the area immediately downstream of an outfall. However, reduced flow will reduce the dilution of downstream point sources thereby increasing the relative bacteria populations in those areas. At higher flows, the bacteria concentration would be lower due to dilution.

In conclusion, the diversion in the Millers River is not believed to generate any significant water quality impact in terms of water quality standard violations assuming that the minimum flow is maintained in the river.

Currently, water quality in the East Branch of the Tully River and Tully Lake is good. The hydraulic residence time of Tully Lake will not be affected by the water diversion since the withdrawal will be located near the existing outlet. No change in the trophic status of Tully Lake will occur.

The dissolved oxygen levels in the Tully River are well above the minimum standard. During two recent surveys completed by the MDWPC, dissolved oxygen levels averaged 7.9 mg/l during June and August surveys with flows of 22 cfs and 10 cfs respectively. Since no diversion will occur at such low flows, and since there are no point source discharges into the Tully River, the dissolved oxygen level is expected to remain above the levels found during those two surveys.

The Tully River contributes between 19 and 28 percent of the Millers River flow (monthly averages based upon 40 years of records). However, the direct impact on the Millers River, due to diversion of water from the Tully River will be small since flow transfer rates from the Tully River will be relatively small compared with the base flow (during periods with flows above the minimum) in both rivers. In addition, the length of the Tully River to be impacted is relatively short (four miles) since the river joins the Millers River immediately downstream from the diversion point in the Tully River. The water quality impact on the Tully River downstream of Tully Lake, and the combined Millers/Tully withdrawal on the Millers River, is expected to be minimal.

6.21.3 Summary of Significant Impacts

The key factor in assessing water quality impacts from a diversion of the Millers River or the Millers and the East Branch of the Tully River is the imposition of minimum flow requirements. Since the regulated minimum flows are sufficient to protect water quality for purposes of maintaining aquatic life, there will be no adverse impacts

during low flow conditions. There will, be small but measurable impacts on the dissolved oxygen levels. The greatest dissolved oxygen impact is expected to be a 0.2 mg/l decrease during flows of approximately 150 cfs in summer months. This reduction, however, will not significantly degrade the water quality of the Millers and, in general, the water quality is expected to remain good with the diversion.

I. Measures of Significance - Measures of Significance used to assess the impacts of transfers from the Millers and Tully Rivers on water quality included constituents affecting public health, aquatic habitats and aesthetics. The water quality of the Millers and Tully Rivers and factors influencing it have been identified and compared to present and projected water uses and classifications. The impact of the project on water quality (concentration changes) was evaluated based on standards and criteria established to assess the present and projected uses of the river. The parameters considered in the impact assessment have included all water quality constituents for which there are sufficient data. These constituents are listed in Tables 6.21-4 and 6.21-5.

II. Significant Impacts - The significant issue in this alternative is that up to 70 cfs of the Millers River flow will be diverted on an average annual basis. However, water quality impacts are not anticipated to be significant, especially due to the low frequency of withdrawals allowed during the biologically critical summer months.

6.21.4 Mitigation/Enhancement Measures

Flow from the Millers or East Branch of Tully will only be diverted if the minimum required flow is met. Since this minimum required flow is greater (in most critical months) than the average flow, this assures that water quality conditions will not be significantly impaired.

6.22 WATER QUALITY OF RESERVOIRS

6.22.2 Future Conditions With Alternative - The impact of the diversion of Millers and Tully River waters into Quabbin Reservoir on the water quality of Quabbin Reservoir is a function of (1) the limnological processes which characterize large impoundments, (2) the quantity and quality of diverted riverine waters, and (3) the operation of Quabbin Reservoir with respect to withdrawal rates and reservoir level.

For purposes of this assessment, it is useful to consider two types of potential impacts: impacts on aesthetics, and impacts on public health. Aesthetic impacts include impacts of such parameters of water quality as color, turbidity, and algal blooms. Public health impacts include impacts on public health due to microbes (bacteria and viruses) and potentially toxic chemicals (organic and inorganic).

- Aesthetic Impacts

  Concentrations of nutrients (which support algal growth) and other constituents of water quality in Quabbin Reservoir will depend, under this alternative, on the hydrodynamics of the reservoir as well as on those physical, chemical and/or biological processes that characterize the natural treatment capacity of the reservoir.

  Safe yield calculations for Quabbin Reservoir using trial yields with and without the alternative indicated that average monthly difference in the elevation of the pool is one foot (BCB) and two feet (BCB) for Millers and Millers/Tully, respectively (see Section 6.11 Hydrologic Modeling).

  An estimate of key hydrodynamic characteristics of the reservoir under this alternative was achieved by means of a computerized simulation (EAI, 1983; see Appendix, Hydrodynamic Diversion Simulations). This simulation included consideration of wind velocity, duration and direction, thermal profiles in the reservoir, and entry of diverted Millers River waters into various locations on the reservoir.

  During simulation, Millers River water diverted into Quabbin Reservoir was given a numerical dye concentration of 100 mg/l. Subsequent concentrations of dye were projected at different depths and locations in the reservoir. Results of the computerized simulation indicate that Millers River waters diverted into the northern branch of the

reservoir first arrive at Shaft #12 about 60 days after initial diversion, and at the Chicopee Aqueduct about 80 days after initial diversion. Upon the arrival of riverine water, the concentration of river water at both locations is reduced approximately 90% due to dilution with ambient reservoir waters. Thus, chemical or physical materials having a concentration of 100 parts/l in Millers River water diverted into the northernmost portion of the reservoir will have a concentration of about 10 parts/l at Shaft #12 and the Chicopee Aqueduct 2-3 months after diversion.

It should be noted that transit time is not equivalent to residence time. Transit time is the smallest interval of time for water to travel from one place to another in the reservoir. Residence time is an average period of time in which a large volume of water remains in one location in the reservoir.

The simulation from which these results were derived is based on the assumption that the chemical and physical constituents in diverted Millers River waters do not undergo dynamic transformations or otherwise settle out in the reservoir. Because of this assumption, the above results may be viewed as "worst case" estimates. In the real situation, sedimentation and physical, chemical and/or biological transformations of water quality constituents will occur. Thus, final concentrations at Shaft #12 and the Chicopee Aqueduct will be even less than those discussed above. It should be noted that the hydrodynamic characteristics of the reservoir which underlie the simulation discussed above are expected to remain essentially constant down to the minimum pool level (490 feet elevation) of Quabbin Reservoir (see Task 4: Interim Technical Report, Determination of the Quabbin Reservoir Minimum Pool Elevation).

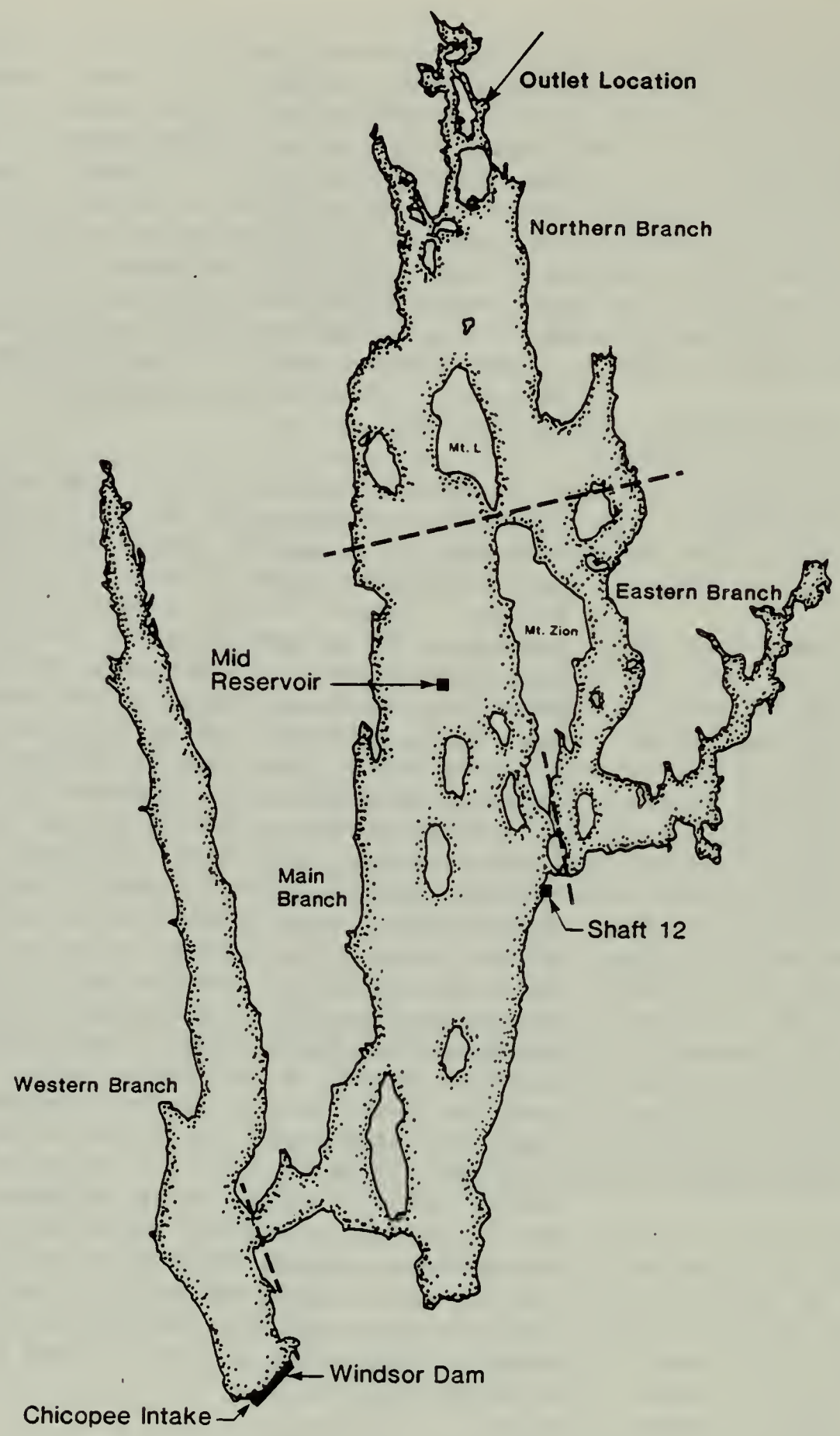
On the basis of the results of the simulation studies discussed above, it is evident that nutrient concentrations in the main branch of the reservoir will increase only slightly within the first several years after diversion. Thus, it is highly unlikely that algal blooms will occur in the main branch of the reservoir. Of course, there is likely to be some enhancement of algal growth in Quabbin Reservoir due to the ambient concentrations of nutrients in the Millers River. An enhancement of algal growth could result in increased turbidity and color in the reservoir. It is impossible to predict precisely just what the level of enhancement would be on the basis of the existing data base. Previous mixing studies of Quabbin Reservoir and Connecticut River waters (see

Task 4 Technical Appendix) did not result in enhanced algal growth in spite of elevated concentrations of nutrients in the Connecticut River. Thus, no attempt is made to predict the enhancement of algal growth under this alternative. If Quabbin Reservoir is maintained at an elevation greater than or equal to 490 feet, it is highly unlikely that enhanced algal growth and subsequent increases in color or turbidity will require treatment in order to meet the Massachusetts Water Quality Regulations at Shaft #12 or the Chicopee outlet. This estimate is based on the extremely high dilution potential of the reservoir (EAI, 1983).

It is important to note that some degradations of water quality will occur in the northern branch of the reservoir (location of diversion) within very short periods of time after initial diversion (Figure 6.22-1). In particular, turbidity and color will increase. It is also expected that most turbid particles entrained in diverted waters will sediment out in the northern branch of the reservoir prior to the entry of diverted water into the main branch of the reservoir. Color due to dissolved materials in diverted waters is also expected to decrease through natural treatment processes in the northern branch of the reservoir. Of course, nutrients released into the northern branch of the reservoir will result in enhanced algal growth which will result, in turn, in higher values of turbidity and color than are expected under the No Action baseline projections (see Task 4: No Action Alternative Assessment Report). It should be noted that hydrodynamic simulations by means of the EAI hydrodynamic model may be used to provide more precise imput into the above assessments. However, if such simulations are run in the future, it will be necessary to utilize a wide range of decay rates and/or transformation rates inclusive of the biogeochemical processes characteristic of lacostrine ecosystems. In the absence of such studies, and on the basis of experience with the water quality of the reservoir, we estimate that the above changes in water quality parameters in the northern branch will be on the order of 10-20%.

- Public Health Impacts

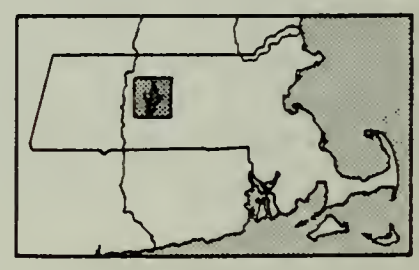
The times of flow from the northern portion of the reservoir to Shaft #12 and the Chicopee Aqueduct indicated by the computer simulation studies are sufficient to ensure the die-off of potentially pathogenic bacteria, protozoa and viruses which may be



Legend

- ----- Approximate Branch Limit
- ■ Sampling Station

Figure 6.22-1.
Location of Water Quality Assessment Stations on Quabbin Reservoir



entrained in diverted waters. Generally, periods of several weeks are sufficient for this purpose.

Although data are limited known concentrations of potentially toxic chemicals (i.e., organic and inorganic) (where data are available) in Millers/Tully River waters are very low or undetectable (see Section 6.21). The low or undetectable concentrations of these materials, and the high dilution potential of Quabbin Reservoir help ensure a low probability for adverse impacts on public health as a result of this alternative.

Finally, Millers River waters have slightly higher values of pH and alkalinity than waters in Quabbin Reservoir. Also, there is concern that the phenomenon of acid rain may be contributing to the acidification of Quabbin Reservoir. This is an important consideration because acid waters enhance the solubility of potentially toxic metals in the pipes of distribution systems. The mixture of Millers River waters with waters in Quabbin Reservoir will result in slight increases in pH and alkalinity (less than 10%), thereby possibly improving the capacity of the reservoir to buffer acidification due to acid rain. This improvement in the buffering capacity will not be as significant as in the case of the Connecticut River Alternative (see Task 5: Connecticut River Assessment Report).

- Impacts on Water Quality in Other Reservoirs

  There will be no public health impacts of this alternative on Wachusett or Sudbury Reservoirs. The slight enhancement of eutrophication in Quabbin Reservoir is highly unlikely to have any impact on the aesthetic quality of water in Wachusett Reservoir. Thus, current and projected operation of the Wachusett Reservoir will not be influenced by this alternative. In the absence of any change in current and projected operation of Sudbury Reservoir, ths alternative will have no impact on water quality in Sudbury Reservoir.

6.22.3 Summary of Significant Impacts

I. Measures of Significance - Key measures of significance include (1) the probability that an impact will occur, (2) the magnitude of the impact, and (3) the duration of the impact. These measures are discussed in detail in the literature on impact assessment (Camougis, 1980; Erickson, 1979) and are summarized in a Technical Appendix).

II. Significant Impacts - Because of the natural treatment capacity of Quabbin Reservoir and its high dilution potential, there will be no significant adverse public health impacts of this alternative. However, if the level of Quabbin Reservoir is allowed to reach less than 490 feet elevation, it is possible that turbidity and color values at Shaft #12 and Chicopee Aqueduct may exceed the appropriate standard. A slight beneficial public health impact of this alternative will be to enhance the pH-buffering capacity of the reservoir.

The alternative will result in an overall increase in the eutrophication of Quabbin Reservoir. The results of an enhanced eutrophication (i.e., enhanced algal growth) will be most evident in the shallower, northern branch of the reservoir which will receive the highest concentration of Millers River water. Also, the northern branch will receive the highest concentrations of suspended particles. It is unlikely that these impacts will be significant adverse impacts on the aesthetic quality of the reservoir. This is based on the premise that the northern branch will not appear dramatically different from other portions of the reservoir which are currently considered to be highly aesthetic.

6.22.4 Mitigation/Enhancement Measures

If the level of Quabbin Reservoir is maintained at an elevation of less than 490 feet, it may be necessary to consider treatment of water prior to delivery to the consumer.

If the level of Quabbin Reservoir is maintained at an elevation greater than or equal to 490 feet, water quality will be slightly lower than water quality projected under the No Action baseline condition. Expected changes in water quality in the main branch of the reservoir are expected to remain within the Massachusetts Water Quality Regulations for Class A Waters.

However, should it be desired to avoid even these relatively small degradations in water quality, it would be necessary to treat diverted waters prior to entry into the reservoir for turbidity, phosphorus and nitrogen. The larger degradations in water quality expected in the northern branch of the reservoir can only be mitigated by treatment of diverted waters as discussed above.

There is no universally accepted method for reversing the effects of enhanced eutrophication in a large reservoir such as Quabbin Reservoir once the enhanced eutrophication has occurred.

6.30 ECOLOGY

In this chapter, the focus is on the ecology of the Quabbin, Wachusett and Sudbury Reservoirs; the ecology of the Millers and Tully Rivers; and the ecology of the tunnel right-of-ways.

6.32 AQUATIC ECOLOGY OF RESERVOIRS

6.32.1 Baseline Conditions

Detailed data on the baseline conditions of Quabbin and Wachusett Reservoirs are included in Section 4.30 and the Task 4: Interim Technical Report, Determination of the Quabbin Reservoir Minimum Pool Level. Detailed data on the baseline conditions of Sudbury Reservoir are included in the Task 9: Upper Sudbury Watershed Assessment Report.

6.32.2 Future Conditions With Alternative

For purposes of this assessment, indicator species were selected (see Task 4: Indicator Species Selection, Interim Technical Report). Indicator species selected for this alternative include some of the indicator species selected under the No Action Alternative (see Table 6.32-1 and Table 6.32-2). These species represent a range of habitat requirements, ecological niches and tolerances and could therefore reasonably be expected to reflect major types of potential impacts, including (1) decline in water quality, (2) decline in water quantity, (3) habitat loss and/or change, and (4) displacement and/or disruption.

Finally, it should be noted that this assessment is based on the assumption that the level of Quabbin Reservoir will be maintained at or above the Quabbin minimum pool level of 490 feet.

As discussed in Section 6.20, nutrient concentrations in the Millers River are higher than ambient concentrations in Quabbin Reservoir. Mean observed phosphorus concentration in the Millers River is about 0.25 mg/l and mean observed ammonia plus nitrate concentration in the Millers River is about 0.62 mg/l. The diversion of Millers River water into the reservoir will therefore result in an enhanced eutrophication of the reservoir. This is based on a variety of data which clearly indicate that Quabbin Reservoir is primarily phosphorus limited, but can also respond to enrichment by nitrogen. (See Technical Appendix for additional data on phosphorus and nitrogen in the Millers River.)

One of the most direct symptoms of enhanced eutrophication is the increase in algal growth. Given the high dilution potential of Quabbin Reservoir, it is unlikely that there will be a measurable increase in algal densities in the main branch of the reservoir within 1-2 years of diversion. However, within 5-10 years of diversions, it is likely that there will be a measurable increase in algal densities in the main branch, which currently range from 100-300/ml in the summer period. Total algal densities achieved in this

TABLE 6.32-1 INDICATOR SPECIES SELECTED FOR THE MILLERS & TULLY RIVER ALTERNATIVE AQUATIC ECOLOGY ASSESSMENT OF RESERVOIRS[1]

		Habitat Type	Trophic Level
Fish			
Redbreast Sunfish	Lepomis auritus	open water	primary carnivore high order carnivore
Atlantic Salmon	Salmo salar	open water	primary carnivore high order carnivore
Sea Lamprey	Petromyzon marinus	open water	high order carnivore[2]
Macroinvertebrate			
Inverted Floater	Alasmidonta heterodon	open water	detritivore herbivore carnivore[2]
Population B Scud	Crangonyx pseudogracilis	open water	detritivore[3] herbivore
Yellow River Mucket	Lampsilis cariosa	open water	detritivore herbivore carnivore[2]
Phytoplankton			
Diatoms	Pennales	open water	primary producers
Zooplankton			
Water Fleas	Cladocera	open water	detritivore herbivore primary carnivore

[1]Source: Task 4: Indicator Species Selection, Interim Technical Report, June, 1983.

[2]Parasite on fish during part of life cycle.

[3]Scavenger of all kinds of plant and animal matter.

TABLE 6.32-2: RESERVOIR AQUATIC INDICATOR SPECIES FOR MILLERS/TULLY RIVERS ALTERNATIVE BY TROPHIC LEVEL AND HABITAT TYPE

	Habitat Type			
Trophic Level	Open Water	Forest Land	Wetland	Open Land
Detritivore	Inverted Floater Water Fleas Population B Scud Yellow River Mucket	Not Applicable	Not Applicable	Not Applicable
Primary Producer	Pennales	Not Applicable	Not Applicable	Not Applicable
Herbivore	Inverted Floater Water Fleas Population B Scud Yellow River Mucket	Not Applicable	Not Applicable	Not Applicable
Primary Carnivore	Redbreast Sunfish Atlantic Salmon Water Fleas	Not Applicable	Not Applicable	Not Applicable
Higher Order Carnivore	Redbreast Sunfish Sea Lamprey Atlantic Salmon	Not Applicable	Not Applicable	Not Applicable

period, although higher than current densities, will still be within the range which is typical of oligotrophic (i.e., nutrient poor) waters, less than 1000 cells/ml.

The northern branch of Quabbin Reservoir will be the initial receiver system for all diverted waters. Therefore, nutrient concentrations in this branch during the summer will be higher than concentrations in the main branch (probably +20-30%). Algal densities will also be correspondingly higher. It is likely that enhanced algal growth in the northern branch of the reservoir will occur within 2-5 years of initial diversion. Expected densities will be comparable to the higher range of oligotrophic waters and the lower range of mesotrophic waters.

It is possible that the impacts of diversion on algal growth in the reservoir will also be influenced by the phenomenon of acid rain. For example, it is possible that continued incidents of acid rain in New England will result in an increased acidification of the reservoir. However, diversion of slightly more alkaline Millers River waters into Quabbin Reservoir would tend to retard the rate of reservoir acidification due to acid rain. Generally, blue-green algae do not occur in waters having low pH but are common in waters having pH greater than 7.

It is highly likely that the northern branch of Quabbin Reservoir will experience an increased rate of sedimentation due to the sediment loading of Millers River waters. Sedimentation of these materials in the northern branch of the reservoir will result in an altered benthic habitat. It is possible that organic sediment will also result in decreased oxygen concentrations at the water-mud interface in some areas in the northern branch. However, it should be noted that many areas in the northern branch of the reservoir currently have large deposits of organic sediment. Thus, sedimentation in the northern branch of the reservoir will not significantly alter the benthic ecology of the reservoir.

Any reduction in concentration of dissolved oxygen in the reservoir due to the BOD of diverted waters is highly unlikely. This is due to the relatively low values of BOD in riverine waters and the mechanical agitation of diverted waters during diversion.

If the lamprey eel becomes established in the Millers River, it is highly likely that lamprey eel will be entrained in diverted waters and enter Quabbin Reservoir. The eels will act as predators on the current fisheries in the reservoir. Impacts of the lamprey eel on the overall aquatic ecology of Quabbin Reservoir are likely to occur over a relatively long period of time (5-10 years), and

will not be significant within short period of time (less than 5 years). Elaboration on the introduction of the lamprey eel in Quabbin Reservoir is also discussed in the aquatic ecology of the Millers River section.

Finally, the enhancement of algal productivity in the reservoir, which is likely to occur as a result of the diversion, will have an overall positive impact on the game species of fish in the reservoir. The increase in algal biomass will enter into the various grazing and detritus food chains which support these fish species. It is impossible to predict the increase in numbers or body weights of fish species which may occur as a result of the enhanced productivity of the reservoir. However, the increases in concentrations of nutrients in the reservoir as a result of the diversion will be relatively small. Thus, the increases in algal densities and, subsequently, grazing and/or carnivorous populations will also be relatively small. It is highly unlikely that any major positive impact on fisheries will be discernible within the first 5 years after the initial diversion.

The relatively small enhancement of the rate of eutrophication of Quabbin Reservoir may have some impact on the water quality of Wachusett Reservoir. For example, enhanced algal growth in Quabbin Reservoir will result in higher color and turbidity in waters taken from Shaft #12 into Wachusett Reservoir. Thus, the dilutional effect of Quabbin water in Wachusett Reservoir will become somewhat less pronounced. However, the expected slight changes in water quality in Quabbin Reservoir are not expected to result in significant or measureable changes in the aquatic ecology of Wachusett Reservoir. Of course, it is highly likely that any undesireable species (i.e., lamprey eel) which are transferred into Quabbin Reservoir by the diversion will also be transferred to Wachusett Reservoir via Shaft #12.

There will be no direct impact of this alternative on the aquatic ecology of Sudbury Reservoir. Changes in water quality or aquatic ecology in Quabbin and Wachusett Reservoirs due to the diversion will not influence the operation of Sudbury Reservoir. Thus, there will be no direct impacts of this alternative on the aquatic ecology of Sudbury Reservoir.

6.32.3 Summary of Significant Impacts

I. Measures of Significance - Measures of significance include (1) the probability that an impact will occur, (2) the magnitude of the impact, and (3) the duration of the impact. In addition to these measures, it is important to

consider the following issues with respect to the assessment of ecological impacts:

- predator/prey relationships (including undesirable species)
- primary productivity
- community structure (including indicator species)
- nutrient cycling

Generally, changes in these key aspects of aquatic ecosystems which are likely to be of long-term duration are considered ecologically significant. However, impacts may be ecologically significant but not socially significant. For purposes of this assessment, the focus is on ecologically significant impacts.

II. Significant Impacts - The significant impacts which are likely to occur as a result of this alternative are presented in Table 6.32-3 and can be summarized as follows:

- slight enhancement of the rate of eutrophication in Quabbin Reservoir
- possible introduction of undesirable species into Quabbin Reservoir
- slight neutralization of the pH of Quabbin Reservoir

6.32.4 Mitigation/Enhancement Measures

While there are many physical, chemical and biological techniques for mitigating eutrophication, there is no consensual method which can ensure the reversal of eutrophication in a large impoundment such as Quabbin Reservoir. The most effective means of dealing with undesirable effects of eutrophication is to prevent its occurrence. Such an approach, in this alternative, would require the treatment of diverted water prior to its entry into Quabbin Reservoir in order to remove dissolved and particulate nutrients. However, we do not consider that eutrophication of Quabbin Reservoir, even at enhanced levels considered under this alternative, will prove to be a significant water quality problem.

Mitigation of adverse impacts on reservoir ecology would most easily be approached by excluding fish ladders from the final dam design. However, this approach does not guarantee the exclusion of lamprey eel from the river. It is important to note that screening methods at the point of intake cannot realistically be trusted to achieve 100% exclusion of the lamprey eel from diverted waters. Filtration of diverted waters followed by reverse osmosis may be considered for its cost effectiveness. In-reservoir treatment may include selective piscidides or biological control mechanisms. A solution that has proven effective

TABLE 6.32-3: PROJECT IMPACTS OF MILLERS/TULLY RIVERS ALTERNATIVE ON AQUATIC ECOLOGY OF RESERVOIRS

Impact Categories	Habitat Type - Open Water
Erosion	Construction of diversion may result in some localized turbidity due to run-off from construction site. Not expected to be significant.
Water Quality	Increase in nutrients in the northern branch of Quabbin leading to increase in algal growth and increase in eutrophication of reservoir. Some increase in color and turbidity, though with dilution potential of Quabbin (about 10 times), this is not expected to be significant. Unlikely that these minor changes in water quality in Quabbin will affect water quality in Wachusett.
Water Quantity	No changes in water quantity expected.
Water Level	No changes in water level expected
Habitat Loss or Change	Settling of organic turbid particles from the Millers River diversion may affect the benthic community, in the northern branch of the Quabbin. Significant impacts unlikely as many areas of northern branch already have large deposits of organic sediment.
Displacement and Disruption	Disruption of finfish species by introduction of lamprey eel through entrainment is very possible. Likely that magnitude of disruption will increase over time.
Entrainment	Entrainment of lamprey eel is probable within five diversion cycles, and damage to fisheries will begin to occur shortly thereafter. Once introduced, lamprey eel will be difficult to erradicate and will have to be controlled within Quabbin and probably Wachusett Reservoirs.
Vegetation Composition Changes	Increases in algal blooms in the northern branch are likely due to increased nutrients from the Millers River diversion. Some increases of algal blooms in the main branch of Quabbin may also occur but are not expected to be significant.

in the Great Lakes is monitoring of the lamprey population and controlling the lampreys in the ammocoete stage in the spawning areas.

If this alternative is chosen as part of the preferred, a limnological study of Quabbin Reservoir should be designed which would allow for more detailed projection of water quality parameters in the various basins of the reservoir with the diversion. This information will help to review the decision whether to provide water treatment. This analysis should incorporate hydrodynamic modeling work, hydrologic modeling of the reservoir, a nutrient budget of the reservoir and a field sampling program to monitor water quality parameters at various depths in the reservoir.

6.33 TERRESTRIAL ECOLOGY OF THE MILLER'S RIVER FLOODPLAIN

An assessment of the vegetation, herpetofauna, avifauna and mammals of the Millers River floodplain was conducted. The study area for this assessment included a section of the Millers River between a point approximately 1.5 miles above the proposed transfer at Athol to the confluence of the Connecticut River at Turner's Falls pool (Figure 6.33-1). This is the section of river that could be affected by a flow reduction of more than 5% as a result of the transfer. For purposes of this assessment, effects resulting from flow reductions of 5% or less are considered insignificant since such flows are within the range of yearly variability. Based upon a 40 year record, the average annual minimum and maximum flows in the Millers River are 33.3 and 1680 cfs respectively. Flow variation within any given year can, of course, exceed this average range.

6.33.1 Baseline Conditions

Baseline conditions are considered to be the conditions existing in 1980 or inferred from the field investigations and projected to 1990, 2000 and 2020 without the project. The assessment of existing conditions was based both on studies conducted by other investigators and upon field investigations conducted in 1982 by NAI. Future conditions were projected based on land use trends. Literature cited is listed in Terrestrial Ecology Appendix Section 6.33.3. Descriptions of field methods, lists of plant and wildlife species and quantitative data are presented in Terrestrial Ecology Appendix Section 6.33.2.

I. Existing Conditions - In the following sections, previous investigations applicable to the Millers River floodplain are presented by groups of biota, and the results of field investigations conducted in 1982 are discussed by vegetative community (habitat type).

- Literature Surveys
  - Vegetation
    - Regional Vegetation - Based on investigations of the regional vegetation by Braun (1972) the study area lies within the Hemlock-Hardwoods area of the New England section of the Hemlock-White Pine-Northern Hardwoods Region. The Hemlock-Hardwoods area is widespread throughout central New England, and lies within the New England Upland Physiographic area which is hilly, with numerous lakes, providing a diversity of environments for plant communities (Lull, 1968). The Hemlock-Hardwoods area is characterized by a

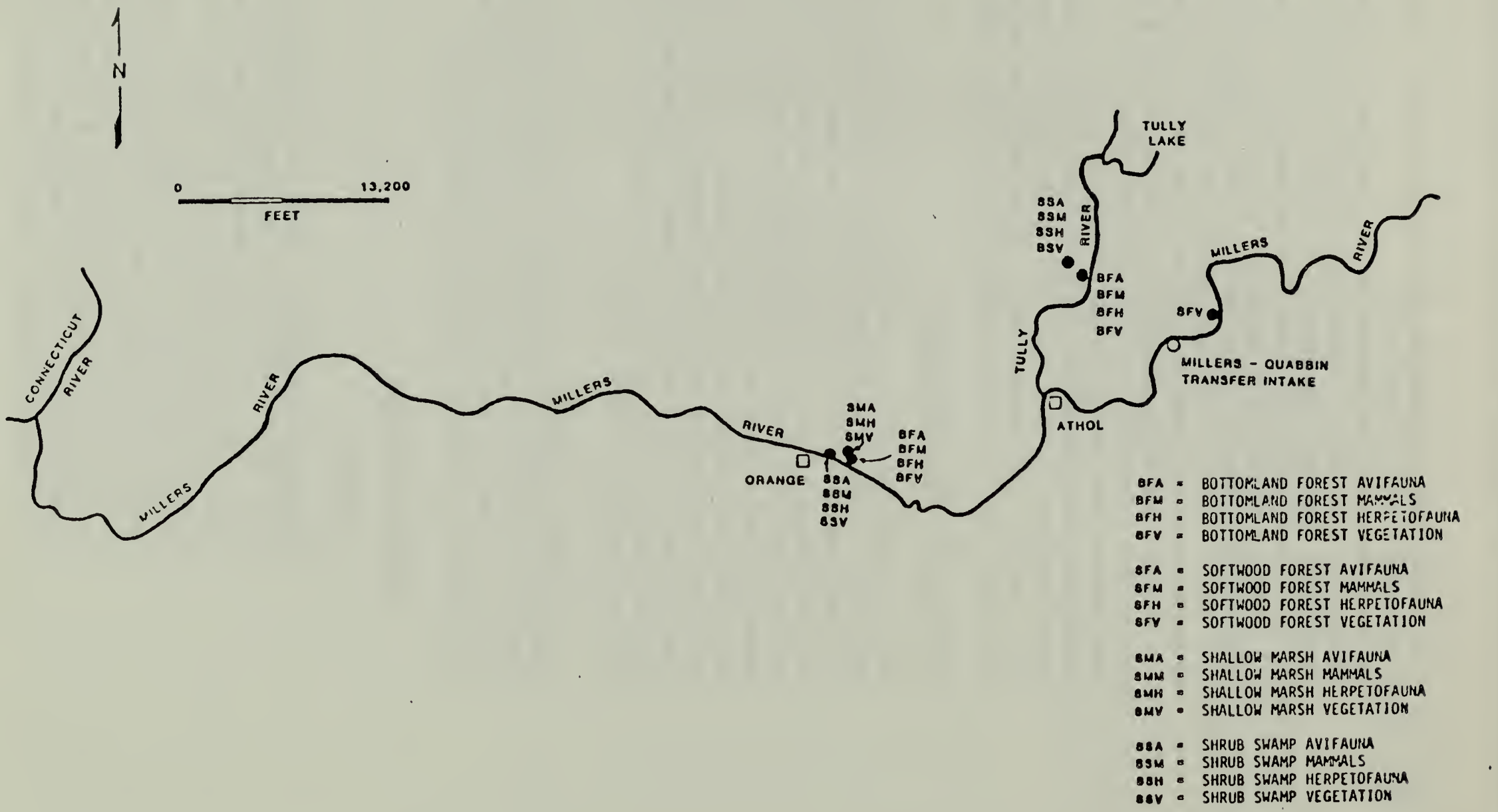


Figure 6.33-1. Floodplain Community Stations on the Millers and Tully Rivers sampled by NAI in 1982.

predominance of second-growth stands that vary widely in species composition depending upon soils and land use characteris- tics. In shrub-lands gray birch and aspen, often in combination with white pine, are generally dominant. Forests that were logged may support stands containing multiple stemmed red oak. On northern slopes or moist sites hemlock may be abundant, or a climax community of hemlock, white pine, beech, yellow birch and sugar maple may be present. Wetland and floodplain communities also vary considerably in species composition depending upon water depth and frequency of flooding.

- Floodplain Vegetation - No previous investigations on the floodplain vegetation of the Millers River are known to have been conducted.

- Herpetofauna - No prior herpetological investigations have been conducted on the Millers or Tully River floodplains, between Tully Lake and the mouth of the Millers River. A list of the New England species having ranges that overlap the study area was obtained from Conant (1975), and Lazell (1972). The lists of state rare and local species were obtained from Blodget and Cardoza (1982).

  The habitat and feeding information for this study was also obtained from the above sources, with additional information taken from the species accounts in Lazell and Michener (1976), Wright and Wright (1949 and 1957), Bishop (1941), and Carr (1952).

  The study area for this alternative lies at the northern limit of the range of several species, notably the spadefoot toad (Scaphiopus holbrookii), and hognose snake (Heterodon platyrhinos), and is typified by more northern, hardy species, adapted to the severity of northern winters. Of approximately 34 species ranging over this area, there are 5 turtles, 11 snakes, 8 salamanders, and 10 frogs.

- Avifauna - Information pertaining to breeding ranges of bird species was obtained from Peterson (1980), and from the Breeding Bird Atlas survey conducted between 1974 and 1979 by the Massachusetts Audubon Society. Specific lists were compiled for this study area by carefully evaluating the later source and including each

species classified under "probable breeding record" status. In the evaluation of this data the emphasis was on including all possible species in the baseline species list for the study area.

The Breeding Bird Atlas is compiled based on areas occupying one sixth of a USGS Topographic map, being rectangular in shape and measuring about three miles on each side. Wherever the floodplain included such an area, the atlas list of breeding species was added to the study list.

The avifauna of the Millers and Tully River study area typically shows a mixture of several types of birds:

1. Water-dependent species, including waterfowl, marsh and swamp birds, and gulls;

2. Northern species at the southern limit of their breeding ranges, such as northern junco, white-throated sparrow, yellow-rumped, mourning, and Canada warblers.

3. Species adapted to artificial food supplies, such as house sparrows, pigeons, and starlings;

4. Wide-ranging resident species, such as the woodpeckers, crows and jays, and titmice;

5. Wide-ranging migrant species, including most of the warblers, vireos, and fringilids (finches, sparrows, buntings, and grosbeaks).

Of primary concern to this project are the first two categories, since impacts to water level or quality may alter the ecology of water-dependent species or species at the limit of their breeding ranges.

- Mammals - The mammals of the Millers River region are a mix containing both boreal (northern) and more typically southern species (Hall and Kelson, 1959). Records compiled by the Massachusetts Division of Fisheries and Wildlife indicate that at least 50 species of mammals may occur in the area (Cardoza, 1979). Evidence for the existence of three additional species (Indiana bat,

European hare, and mountain lion) is inconclusive (Cardoza, 1979).

Blodget and Cardoza (1982) list four nongame mammal species from this region for "special consideration" (protection): water shrew, Indiana bat, hoary bat, and southern bog lemming. The Indiana bat is a federally endangered species. The water shrew and southern bog lemming are listed because of their highly localized distribution. The hoary bat migrates through Massachusetts, but its status as a breeding resident is unknown.

- Field Surveys - Owing to the steepness of the banks aligning both sides of the river within the study area, wetland and floodplain communities were much less common than the terrestrial communities; although, there was sufficient wetland and floodplain area to select representative locations. In the following subsections, the results of the field investigations, conducted at locations representative of the floodplain and wetland communities in the study area, are discussed for vegetation, herpetofauna, avifauna and mammals. Terrestrial communities were not included because the project would affect only floodplain and wetland types. River channel and bottom communities were also not included because water level reduction will not be great enough to affect these types. The locations of the transects where the studies were performed are shown in Figure 6.33-1. The habitat types are presented by plant successional stage, where appropriate, beginning with the earliest stage. Similarly, the groups of wildlife are presented beginning with the most primitive group. Complete species lists and data are presented in Terrestrial Ecology Appendix Section 6.33.2. In general, the flora and fauna found to be present in the floodplain and wetland types of the study area were representative of the plant and wildlife communities of central New England. These types include shallow marsh, shrub swamp and bottomland forest.

  - Shallow Marsh

  - Vegetation - Shallow marsh is an early stage in wetland succession that develops on both floodplain and upland sites inundated by standing water for a significant part of the growing season. The marsh community in the study area was dominated by three species of emergents, water hemlock (Cicuta bulbifera), cattail (Typha

latifolia) and bur-reed (Sparganium sp.). In addition to the dominants, smaller proportions of other marsh emergents were found including three-way sedge (Dulichium arundinaceum), marsh St. Johnswort (Hypericum virginicum) and arrowhead (Saggittaria sp.). Sphagnum moss (Sphagnum sp.) formed broken patches at the soil surface, and areas of deeper water contained floating plants such as duckweed (Lemna minor), milfoil (Myriophyllum) and bladderwort (Utricularia sp.). A total of 13 plant species were observed in this vegetative type. Being an early stage in plant succession, this type is unstable and, over a period of perhaps 20 years, may be replaced by shrub swamp, the next stage in the successional sequence.

- Herpetofauna - The floodplain of the Millers River yielded several species of herpetofauna. Searching occurred at the time of the bird transects, from May 25 through May 28, 1982.

  The shallow marsh habitats yielded spring peepers (Hyla crucifier), American toads (Bufo americanus), green frogs (Rana clamitans), and bullfrogs (Rana catesbeiana). This habitat is common along the Millers River near Athol and Orange, and is biologically productive.

- Avifauna - One transect was sampled along the edge of a shallow marsh between May 25 and 28, as described in the methods (Terrestrial Ecology Appendix Section 6.33.2), between 05:49 and 07:50 EDT, during periods with no high wind or rain. Overcast skies, light fog and light drizzle were encountered, however these factors were not accompanied by rain or wind, and did not limit the visibility or audibility of nearby birds. Bird activity levels were not reduced in the judgment of the observer.

  Those species found to have the highest densities were, in decreasing order of abundance: red-winged blackbird, warbling vireo, common grackle, yellow warbler, and common yellowthroat.

  In all, 22 species were observed in shallow marsh habitats of the study area.

- Mammals - This habitat type was not trapped because of its wetness. However, the results for both the bottomland forest type and shrub swamp types indicate that white-footed mice and eastern

chipmunks are abundant along its woodland edge. The margins of shallow marshes are also widely used by raccoons for foraging as evidenced by tracks observed during the winter survey. Muskrats are the only species which can be considered permanent residents within this habitat type.

- Shrub Swamp

- Vegetation - This vegetative type develops on both floodplain and upland sites covered by standing water for a significant portion of the growing period. Shrub swamps are often marshes that have become dominated by shrub swamp species during development of the community. In the study area this type was dominated by meadowsweet (Spiraea latifolia), with shrubs such as silky dogwood (Cornus amomum), arrow-wood (Viburnum recognitum) and willow (Salix sericea) scattered in lower abundances. There were 14 other species of shrubs observed throughout this type. In the herbaceous layer, sedges (Carex spp.) were predominant, forming dense growths in the openings. Occurring in lesser numbers were sensitive fern (Onoclea sensibilis), marsh fern (Dryopteris thelypteris) and marsh St. Johnswort. Ten other species including sphagnum, tall meadow rue (Thalictrum polygamum) and violet (Viola sp.) were also found in the shrub swamps throughout the study area. A total of 32 different species were observed in this type. As with the marsh type, shrub swamps are transitional; however, owing to a more complex community structure and longer period of establishment, the rate of change is generally slower. Over a period of perhaps 60 years, some of the shrub swamps may have succeeded to bottomland forest.

- Herpetofauna - Searches were conducted at the same time as the bird transects, however herpetofauna were not observed. The shrub swamp has a surface water connection to the river, and riverine fish may produce a high predation factor on aquatic herpetofauna.

- Avifauna - One transect was placed near the search location mentioned above. The transect was sampled during the same period as those for bottomland forest and for shallow marsh, from May 25-28, between 05:20 and 07:46 EDT. Overcast and foggy weather was encountered during this sampling, but the observations of nearby birds

within this habitat were not hampered, since sound reduction due to wind or rain was not a factor at any time and the birds were found to be normally vocal and active during each sampling period.

The five species having the highest densities in this habitat were found to be: warbling vireo, red-eyed vireo, gray catbird, cedar waxwing and yellow warbler. In all, 32 species were observed on this transect.

Species observed, which are particularly dependent on the river or on the shrub swamp, were: spotted sandpiper, tree swallow, and northern waterthrush.

- Mammals - Four small mammal species were captured in this habitat: short-tailed shrew, eastern chipmunk, white-footed mouse and meadow vole. The white-footed mouse and eastern chipmunk were the two most abundant species, representing 64% and 18% of all captures. The density estimates for both species were quite high; 21.3/ha for the white-footed mouse and 19.3/ha for the eastern chipmunk. Both the short-tailed shrew and the meadow vole were captured in an area along the transect which was more open and had a dense growth of grasses and forbs. Tracks of cottontail (species unknown), domestic dogs, raccoon and mink were all common in this habitat during the winter survey.

- Bottomland Forest

- Vegetation - The bottomland forest type is adapted to the regular cycles of river flooding that occur during the spring growing season, and is the final stage in the succession of the floodplain community. There are three plant growth forms in this type: tree, shrub and herbaceous, which form three layers. In the tree layer of the bottomland forests in the study area, red maple (Acer rubrum) was dominant, with other species such as cottonwood (Populus deltoides) and American elm (Ulmus americana) scattered in lower numbers throughout the tree layer. The shrub layer was dominated by red maple saplings, and shrub species such as buckthorn (Rhamnus frangula), arrow-wood, northern wild raisin (Viburnum cassinoides) and silky dogwood were found scattered throughout the shrub layer in lower numbers. In the herbaceous

layer the dominant species was Canada mayflower (Maianthemum canadense) with species such as royal fern (Osmunda regalis), sedge, Joe-pye-weed (Eupatorium sp.) and sessile bellwort (Uvularia sessilifolia) less commonly observed. There were 51 species of plants observed in this type. Bottomland forest is a stable type that will remain essentially unchanged with respect to structure and species composition provided that spring flooding cycles continue unaltered.

- Herpetofauna - The dates for the field surveys were the same as those mentioned above for other habitats, May 25-28, 1982.

  The species found were spring peepers and a milk snake (Lampropeltis triangulum), although the latter was probably utilizing nearby upland habitats more fully than the bottomland forest.

- Avifauna - One transect was sampled for avifauna in bottomland forest along the Millers River. The times were interspersed among those for the other habitats, and ranged from 05:39 to 08:22 EDT, with weather conditions being the same as those described above.

  The species observed which had the highest computed densities were: veery, least flycatcher, red-winged blackbird, common grackle and robin.

  Species highly dependent on this habitat were: least flycatcher, tree swallow, and Canada warbler.

  In all, 26 species were observed in the bottomland forests of the study area.

- Mammals - Four small mammal species were trapped in this habitat: eastern chipmunk, white-footed mouse, southern red-backed vole, and meadow jumping mouse. The two most abundant species were the eastern chipmunk and white-footed mouse, each representing 38% of the total captures. Density estimates for these species were 4.6/ha and 4.1/ha respectively. The capture of meadow jumping mice along a portion of the transect in this type reflects the presence of herbaceous growth at the forest edge or where openings in the canopy occur. Numbers caught and density estimates for the above four species are presented in Terrestrial Ecology Appendix Section

6.33.2. This habitat was considered ideal for raccoons both because of the maturity of trees which may provide natural cavities for dens, and its close proximity to a shallow marsh and the Millers River. Tracks of cottontail (species unknown), gray squirrel, raccoon, and domestic cat were common in this type during the winter survey.

- Threatened and Endangered Species - No species of plants, herptiles or birds that are of special concern are known to occur in the study area (Massachusetts Natural Heritage Program, 1982). Mammals which have been listed from this region for special consideration include the water shrew and southern bog lemming (state local), the hoary bat (a peripheral breeding species), and the Indiana bat (Federally endangered); the latter two species migrate through Massachusetts (Cardoza, 1982). None of these species have been confirmed to be present in the study area.

- Selection of Indicator Species - From the inventory and analysis of baseline conditions presented in Section 6.33.1, indicator species of plants, herpetofauna, birds and mammals were selected for the Millers River floodplain. The term "indicator species" as applied in this report denotes (1) species representative of floodplain and wetland habitats, and (2) species sensitive to the kinds of perturbations that may result from development of the Millers River alternative.

  The group of species selected is representative of the trophic levels and habitats within the study area and within potential project impact areas; these species will be used to assess impacts of water supply development on these habitats. These species are listed in Table 6.33-1.

  The indicator species were selected on the basis of seven criteria; these criteria and the selection process are presented in the report "Task 4: Indicator Species Selection".

II. Future Conditions Without Alternative - Available information on land use and population to the year 2020 is very limited, and the following analysis is the best possible given the limited data base. Based on the areawide 208 planning study (1977), population is expected to increase very slowly in the towns along the floodplain study area, and associated changes in land use patterns and cover types will be minor. Accordingly, future characteristics of the vegetatively defined floodplain

TABLE 6.33-1. INDICATOR SPECIES SELECTED FOR THE MILLERS RIVER FLOODPLAIN ECOLOGY ASSESSMENT.

PLANTS	SCIENTIFIC NAME	HABITAT TYPE	TROPHIC LEVEL
Red oak	Quercus borealis	Softwood forest Hardwood forest	Primary producer
Beech	Fagus grandifolia	Hardwood forest	Primary producer
White pine	Pinus strobus	Softwood forest	Primary producer
Green ash	Fraxinus subintegerima	Bottomland forest	Primary producer
Sensitive fern	Onoclea sensibilis	Wet meadow	Primary producer
Blue-joint grass	Calamagrostis canadensis	Shallow marsh	Primary producer
Water naiad	Najas flexilis	Shallow marsh	Primary producer
Sweetflag	Acorus calamus	Shallow marsh	Primary producer
Speckled alder	Alnus rugosa	Shrub swamp	Primary producer
Meadowsweet	Spiraea latifolia	Abandoned field	Primary producer
Gray birch	Betula populifolia	Shrubland	Primary producer
WILDLIFE			
American crow	Corvus brachyrhynchos	All habitats listed above	Detritivor
White-throated sparrow	Zonotrichia albicollis	Softwood forest Shrubland	Herbivore
Swamp sparrow	Melospiza georgiana	Shallow marsh Shrub swamp	Herbivore
White-breasted nuthatch	Sitta carolinensis	Hardwood forest Bottomland forest	Primary carnivore
Chestnut-sided warbler	Dendroica pensylvanica	Abandoned field Shrubland	Primary carnivore

TABLE 6.33-1. (Continued)

WILDLIFE	SCIENTIFIC NAME	HABITAT TYPE	TROPHIC LEVEL
Red-tailed hawk	Buteo jamaicensis	Hardwood Forest Softwood forest Bottomland forest Shrub swamp Abandoned field Shrubland	Higher order carnivore
Barred owl	Strix varia	Softwood forest	Higher order carnivore
Great Blue Heron	Ardea herodias	Bottomland forest Wet meadow Shallow marsh Bog, Shrub swamp	Higher order carnivore
Gray squirrel	Sciurus carolinensis	Hardwood forest Bottomland forest	Herbivore
Beaver	Castor Canadensis	Bottomland forest	Herbivore
Meadow vole	Microtus pennsylvanicus	Wet meadow Bog, Shrub swamp Abandoned field Shrubland	Herbivore
Muskrat	Ondatra zibethica	Shallow marsh	Herbivore
Short-tailed shrew	Blarina brevicauda	All habitats listed under "Plants" except Shallow marsh, Bog	Primary carnivore
Pickerel frog	Rana palustris	Shallow marsh, Bog	Primary carnivore
Black rat snake	Elaphe obsoleta	Abandoned field Shrubland	Higher order carnivore

(that portion requiring inundation an average of once a year) will be mainly the result of natural plant community development processes. Since structural and compositional changes in vegetative communities occur very slowly, particularly in wetlands and annual floodplains, differences in site vegetation and wildlife use between the three time periods considered below are expected to be very slight.

- 1990 - The three floodplain communities observed in the study area were shallow marsh, shrub swamp and bottomland forest. Shallow marsh is an early stage in the sequence of wetland and floodplain community development and by 1990 woody plants characteristic of shrub swamp, the next successional stage, may become established. Plant community composition and structure will remain predominantly shallow marsh, although wildlife typically associated with shrub and sapling forms will also begin to utilize the marsh areas, increasing faunal diversity. Shrub swamps are also an early stage but due to a more complex community structure, the rate of change is somewhat slower. It is unlikely that by 1990 this type will have changed sufficiently to significantly affect wildlife species composition, and the fauna will continue to consist of those species typically found in shrub swamp communities.

  Bottomland forest is the final stage in the development of the floodplain community. This type will remain essentially unchanged in terms of species composition provided that the annual flooding cycles continue unaltered, although tree growth will continue. Based on the minor population and land use changes expected, and the slow rates of floodplain community change, conditions in 1990 will differ only very slightly from existing conditions.

- 2000 - By the year 2000, the shallow marshes in the study area will most likely have become dominated by plant species typical of the shrub swamp type. This will provide habitat for wildlife species characteristic of shrub swamp communities. The shrub swamp will most likely not have changed sufficiently by 2000 to affect wildlife species composition, and the wildlife will remain typical of the species found in shrub swamp communities. The bottomland forest stands will remain essentially unchanged except for the growth of individual trees. With these minor exceptions, future conditions along the floodplain study area will not differ substantially from existing conditions.

- 2020 - By 2020, saplings of tree species characteristic of bottomland forest may become established in the shrub swamp growth that will have taken over the shallow marsh community by the year 2000. Due to the more complex community structure of shrub swamp compared to shallow marsh, the rate of change is generally slower and it is likely that shrub swamp will continue to be predominant in former shallow marsh areas by 2020. It is unlikely that the establishment of the saplings will change community structure sufficiently to significantly affect wildlife species composition, and the fauna will remain typical of the species found in shrub swamp communities. In former shrub swamps, however, saplings typical of bottomland forest communities may have become established in sufficient numbers to encourage use by wildlife species typical of this successional stage, which will increase faunal diversity. The growth of the bottomland forest by 2020 may have changed the community structure sufficiently to increase shading which will reduce the density and alter the species composition of understory shrubs and herbs. Wildlife species composition may shift from ground nesting species to wildlife that favor large trees for nesting and/or feeding. With the above exceptions, future conditions along the floodplain by 2020 will not differ substantially from existing conditions.

6.33.2 Future Conditions With Alternative

Future conditions with this alternative are assessed both for the construction period and for three future time periods. Construction period impacts consider immediate effects on plant and wildlife communities, indicator species and species of special interest. Long-term impacts are changes in these communities and species resulting from changes in water quantity and quality. Construction period and long term project impacts on indicator species utilizing potentially affected habitats are summarized by impact category and habitat in the matrix in Table 6.33-2.

I. Short-term Construction Period - A drop shaft constructed near the north bank of the Millers River at the site of the proposed transfer to Quabbin Reservoir, a spoil pile, and construction laydown areas, will require permanent removal of 6.5 acres of mixed hardwood-softwood forest and temporary disturbance (during construction only) of another acre. This plant community is fully described in Section 6.34.1. The plant indicator species that will be affected are red oak and white pine. The wildlife indicator species affected will include a detritivore (American crow), an herbivore (gray squirrel), two primary

TABLE 6.33-2. SUMMARY OF IMPACTS OF THE PROPOSED MILLERS RIVER DIVERSION ON FLOODPLAIN PLANT AND WILDLIFE INDICATOR SPECIES.

	HABITAT TYPE						
Impact Categories:	Hard-wood Domin-ated Mixed Forest	Soft-wood Domin-ated Mixed Forest	Bot-tom Land Forest	Shal-low Marsh	Shrub Swamp	Abon-doned Field	Shrub Land
Erosion		X					
Water Quality							
Water Quantity			X	X	X		
Water Level			X	X	X		
Habitat Loss/ Change		X					
Displacement/ Disruption		X					
Entrainment/ Impingement							
Vegetation Composition Changes							

carnivores (white-breasted nuthatch and short-tailed shrew) and a higher order carnivore (red-tailed hawk) (Table 6.33-1). All five indicator species utilize the mixed forest type to fulfill both feeding and breeding requirements.

Hundreds of acres of the mixed hardwood-softwood type occur in the general vicinity of the floodplain between the tunnel intake and the month of the river. The loss of a small amount of acreage from the area of the tunnel intake will be a minor impact to populations of red oak and white pine, and the surrounding vegetative complex. The loss of this small amount of habitat is not expected to seriously impact the wildlife communities or populations of indicator species that utilize it due to the abundance of the mixed forest habitat type elsewhere in the vicinity of the floodplain. Other stands of mixed forest may also be expected to support populations of the above indicator species, and the impacts are expected to be within the range of tolerance of the indicator species populations and the wildlife communities. There are no plant or wildlife species of special interest known to occur in the vicinity of the tunnel intake.

Limited soil erosion will occur but erosion controls and revegetation measures would be instituted during construction and there will be no significant effect on soil or on vegetation. Effects of short-term erosion on aquatic communities and mitigation for this impact is discussed in Section 6.37.

Very localized, short duration construction impacts on wildlife, such as noise and disturbance will probably occur, however, these impacts are expected to be insubstantial.

II. Long Term - Changes in water level at a representative section of the Millers River floodplain (Terrestrial Ecology Appendix Figure 6.33-2) with the proposed transfers were determined based on 40-year average flow data for April, May and June. April and May are the most important from the standpoint of inundation requirements of the floodplain communities. Throughout the rest of the year, the water level is normally below the floodplain. The average actual transfer for April will be 139 cfs, and for May, 107 cfs (Millers without Tully).

June is when impacts on river channel plants caused by a decrease in water level would be most likely to occur because this is the month in which the river flow at Athol is sufficient for the average actual transfer for that month (42 cfs) approximately 70% of the time while maintaining the 250 cfs low flow requirement. The river

channel plants may be stressed by insufficient water during the remainder of the month, but not to the extent that the potential for project impacts would not exist when Athol flows are sufficient for transfer. In July and August, when flows are insufficient for transfers between 85 and 95% of the time, and the aquatic plants are already under drought stress, project impacts may not be separable from the regularly occurring drought stress. For this reason June was selected as the worst case month, having the greatest number of days that transfers can occur under low flow conditions. The maximum possible June transfer based on simulated actual conditions would be 322 cfs. The requisite river flow condition for this transfer volume occurred only on one occasion throughout 40 years of flow record. This condition was not used for worst case analysis because of its extremely atypical occurrance.

The calculations demonstrated that the net decrease in water level attributed to the proposed transfer to Quabbin Reservoir during April will be approximately 2 inches, resulting in a decrease of approximately 2 feet in the lateral extent of flooding. However, calculations for May show a reduction in stage of approximately one foot which would result in a decrease of approximately 9 feet in lateral extent of flooding on the south bank. Based on the cross section, this reduction would occur in the lower portion of the floodplain, since the average flows for May occupy a point on the floodplain about 5 feet below its boundary with the upland. This is probably the maximum decrease in flooded area within the 5 percent study area because the transect location chosen had the flattest profile.

The April changes are well within the natural daily range of fluctuations. A decrease of 2 feet in lateral flooding will have no observable affect upon green ash, speckled alder, or other floodplain vegetation because the accuracy with which the vegetatively defined floodplain (vegetative community consisting of greater than 50 percent hydrophytic species) can be delineated in the field is much less precise than this. This is because the floodplain/ upland boundary is often indistinct, occurring within a transition zone; this zone is broad at cross sectional areas having a flat profile, narrowing at steeper cross sections.

The May change in lateral flooding could be accompanied by long-term changes in floodplain community structure and species composition. Plant indicator species potentially affected by a reduction in water level are green ash, blue-joint grass, sweetflag and speckled alder. The wildlife species potentially affected by changes in vegetation composition caused by a reduction in water level include a detritivore (American crow), five herbivores

(gray squirrel, muskrat, beaver, meadow-vole and swamp sparrow), three primary carnivores (white-breasted nuthatch, short-tailed shrew and pickerel frog) and two higher order carnivores (red-tailed hawk and great blue heron) (Table 6.33-1). The white-breasted nuthatch, gray squirrel and beaver satisfy the majority of their life cycle requirements, including breeding, in the bottomland forest, whereas the swamp sparrow utilizes the shrub swamp types for feeding and breeding. The other indicator species utilize combinations of marsh, shrub swamp and bottomland forest habitats to fulfill life cycle requirements.

The calculations demonstrate that during June the net decrease in water level attributable to the transfer will be approximately 13 inches, resulting in a maximum decrease of approximately 2.5 feet in the lateral extent of flooding, which will place the water level at the bottom of the floodplain at this location. At this point, which corresponds to the minimum flow of 250 cfs, the water level is still sufficient to fill the river slightly above the top of the channel, however, there will be no observable effect on wetland or river channel vegetation, or upon wildlife habitat. Given a maximum possible June transfer of 322 cfs under conditions of extremely high river flow, the net decrease in water level would be approximately 3 feet. However, water level would still be at or above the level corresponding to the 250 cfs minimum flow constraints which is above the top of the channel.

Since the vegetative communities and plant indicator species could be altered as a result of the May transfer, wildlife feeding and breeding habitats, communities and populations of indicator species could also be affected by shifts in habitat. Field methods, cross section locations and flow/stage calculation methods are presented in Terrestrial Ecology Appendix Section 6.33.2.

- 1990 - Although noticeable reductions in floodplain inundation will be expected during May, significant changes in the floodplain plant and animal communities by 1990 will not have occurred in that time frame and will be as discussed in Section 6.33.1.II.

- 2000 - Because reductions in floodplain inundation will be expected to occur in May as a result of project operation, changes in floodplain communities by the year 2000 are expected which may be accompanied by shifts in wildlife habitat and populations.

- 2020 - Given that the extent of floodplain inundation will be significantly reduced in May, characteristics of the plant and wildlife communities of the shallow

marsh, shrub swamp and bottomland forest types by 2020 may differ substantially from that expected without the project.

6.33.3 Summary of Significant Impacts

Significant long-term impacts to floodplain plant and wildlife communities and indicator species or species may be expected to occur as a result of the proposed transfer.

I. Measures of Significance - Existing water quality baselines were determined and projections with and without the project were made. Changes in water level relative to the floodplains and river channel due to the project were determined based on 40-year average flow data for April, May and June, the most important times of the year with respect to floodplain and river channel inundation requirements. Vegetation and wildlife were identified and their uniqueness relative to the surrounding communities determined. Indicator species representative of floodplain communities which will respond to water level and water quality changes were selected (see "Task 4: Indicator Species Selection"). The uniqueness of the plant and wildlife communities, presence of species of special concern, and sensitivity of these biota and any indicator species to changes in water level or quality were the measures used to judge the significance of project impacts.

II. Significant Impacts - Significant long-term impacts on floodplain vegetation and wildlife may occur as a result of the proposed transfer. However, the area of flat, floodplain severely impacted is small and not unique to the geographical area.

6.33.4 Mitigation/Enhancement Measures

Erosion control during construction is recommended to protect river channel vegetation from siltation.

6.34 TERRESTRIAL ECOLOGY OF THE MILLER'S-QUABBIN TUNNEL R.O.W.

An assessment of the vegetation, herpetofauna, avifauna and mammals of the Millers-Quabbin Tunnel R.O.W. was conducted. The study area for this assessment included the 3 spoil pile locations along the R.O.W. from the proposed transfer at Athol to Quabbin Reservoir (Figure 6.34-1).

6.34.1 Baseline Conditions

Assessments of the existing baseline, and baseline conditions projected to 1990, 2000 and 2020 without the project were made. Literature cited is listed in Terrestrial Ecology Appendix Section 6.34.3 and quantitative data are presented in Terrestrial Ecology Appendix Section 6.34.2.

I. Existing Conditions - In the following sections previous investigations applicable to the Millers-Quabbin Tunnel R.O.W. are presented by groups of biota, and the results of field investigations conducted in 1982 are discussed by vegetative community.

- Literature Surveys

- Vegetation

  - Regional Vegetation - The vegetation of the Millers-Quabbin Tunnel R.O.W. is part of the regional vegetation discussed in Section 6.33.1.

  - R.O.W. Vegetation - No previous investigations of the vegetation of the Millers-Quabbin Tunnel R.O.W. have been conducted.

- Herpetofauna - No prior herpetological studies conducted in either Millers or Tullys R.O.W. corridors have been found. A list of the New England species having ranges that overlap the study area were obtained from Conant (1975), and Lazell (1972). The lists of state rare and local species were obtained from Blodget and Cardoza (1982).

  The habitat and feeding information for this study was also obtained from the above sources, with addi- tional information taken from the species accounts in Lazell and Michener (1976), Wright and Wright (1949 and 1957), Bishop (1941) and Carr (1952).

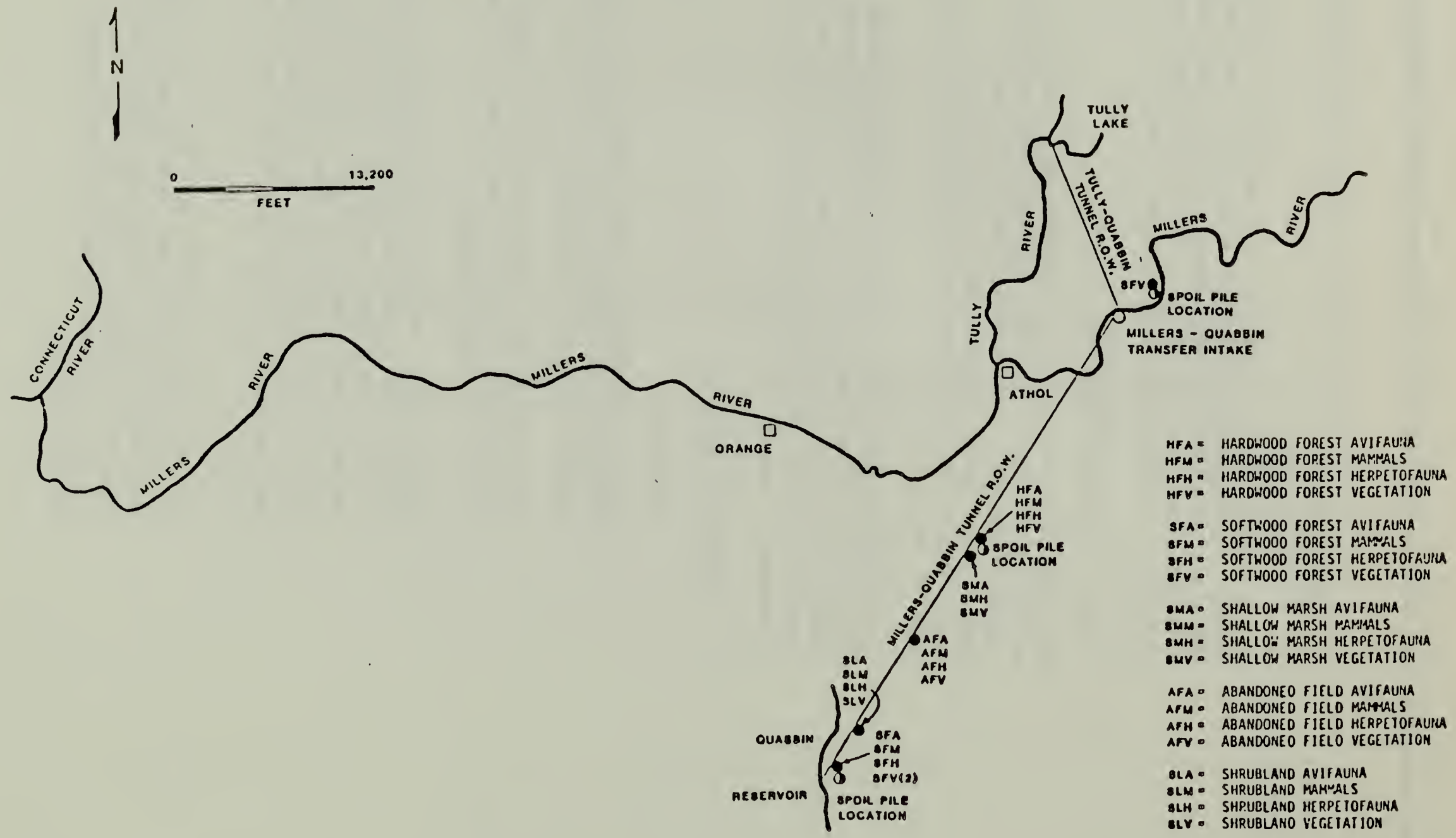


Figure 6.34-1. Terrestrial Community Stations along the Millers-Quabbin Tunnel R.O.W. sampled by NAI in 1982.

The study area for this alternative lies at the northern limit of the range of several species, notably the spadefoot toad (Scaphiopus holbrooki), and hognose snake (Heterodon platyrhinos), and is typified by more northern, hardy species, adapted to the severity of northern winters. Of approximately 34 species ranging over this area, there are 5 turtles, 11 snakes, 8 salamanders, and 10 frogs.

One local expert on Timber Rattlesnake (Crotalis horridus) was consulted for the location of dens along this R.O.W.. None were found in the vicinity of proposed construction areas.

- Avifauna - Information regarding breeding ranges of bird species was obtained from Peterson (1980), and from the Breeding Bird Atlas survey conducted between 1974 and 1979 by the Massachusetts Audubon Society. Specific lists were compiled for this study area by carefully evaluating the latter source and including each species classified under "prob- able breeding record" status. The emphasis in evaluating this data was on including all possible species in the baseline species list for the study area.

The Breeding Bird Atlas is compiled based on areas occupying one sixth of a USGS Topographic map, which is rectangular in shape and measures about three miles on each side. Wherever either R.O.W. included such an area, the atlas list of breeding species was added to the study list.

The avifauna of the Millers and Tullys R.O.W. corridors typically shows a mixture of several types of birds:

1. Water-dependent species, including waterfowl, marsh and swamp birds, and gulls;

2. Northern species at the southern limit of their breeding ranges, such as northern junco, white-throated sparrow, yellow-rumped, mourning, and Canada warblers; (this area, north of Quabbin, contains some excellent, relatively undisturbed habitat for northern species).

3. Species adapted to artificial food supplies, such as house sparrows, pigeons, and starlings;

4. Wide-ranging resident species, such as the woodpeckers, crows and jays, and titmice;

5. Wide-ranging migrant species, including most of the warblers, vireos, and fringilids (finches, sparrows, buntings, and grosbeaks).

All of these categories of birds are of concern in this study area, since construction may alter the ecology of any species. Species at the limit of their breeding ranges (category 2 on previous page), however, are at particular risk, since it is very likely that they are operating near the limit of their niche tolerance, and are therefore more sensitive to construction impacts.

- Mammals - Existing information on mammals for this study area is the same as that already described in Section 6.33 for the Millers River floodplain.

- Field Surveys - In the following subsections, the results of field investigations conducted at locations representative of the R.O.W. habitats in the study area are discussed for vegetation, herpetofauna, avifauna and mammals. The locations investigated included representative areas along the R.O.W. and the vicinities of the three spoil piles. The locations of the study transects are shown in Figure 6.34-1. Where appropriate, the groups of biota are presented by plant successional stage beginning with the earliest stage and most primitive wildlife group. Complete species lists and data are presented in Terrestrial Ecology Appendix Section 6.34.2. Generally, the plants and wildlife occurring in the R.O.W. habitat types of the study area were representative of the types indigenous to central New England. The types found at the three spoil pile locations and along the R.O.W. include shallow marsh, abandoned field, shrubland, hardwooddominated mixed forest and softwood dominated mixed forest.

- Shallow Marsh

- Vegetation - The marsh community contained a predominance of shrub swamp species on the periphery and in scattered patches. The most abundant shrub species were cranberry (Vaccinium macrocarpon) and leatherleaf (Chamaedaphne calyculata), with species such as highbush blueberry (Vaccinium corymbosum), sheep laurel (Kalmia augustifolia) and maleberry

(Lyonia ligustrina) occurring in fewer numbers. The marsh itself was dominated by arrowhead, sedge and marsh St. Johnswort, with sphagnum forming large patches at the soil surface. Occurring in fewer numbers were three-way sedge, spikerush (Eleocharis sp.) and whorled loosestrife. Patches of open water contained bullhead lily (Nuphar variegatum). A total of 27 species of shrubs and herbs were observed in this type.

- Herpetofauna - The shallow marsh type along the Millers R.O.W. was sampled for herpetofauna at the same time as the bird transects, from June 15 through 19, 1982.

  Species observed during this period in the shallow marsh included bullfrogs (Rana catesbeiana) and painted turtles (Chrysemys picta). Both were abundant in this habitat.

- Avifauna - One transect was sampled along the edge of a shallow marsh between June 15 and 19, as described in the methods (See Terrestrial Ecology Appendix Section 6.33.2) between 05:43 and 08:10 EDT, during periods with no high wind or rain. Clouds and light fog were encountered on one day, however these factors were not accompanied by rain or wind, and did not limit the visibility or audibility of nearby birds. Bird activity levels were not reduced in the judgment of the observer.

  Those species occurring in the highest densities were: red-winged blackbird, cedar waxwing, American robin, common flicker, and eastern kingbird.

  Several species were observed which are particularly dependent upon this habitat including: eastern phoebe, tree, rough-winged and barn swallows, cedar waxwing, red-winged blackbird, and swamp sparrow. All but the last two species depend on the insects associated with the marsh biota.

  In all, 26 species were observed in the shallow marsh habitat of the Millers R.O.W..

- Mammals - Although no trapping was done in this habitat type because of its wetness, white-footed mice and eastern chipmunks are expected to be common along any woodland edge bordering a

wetland. Raccoons generally forage along the shoreline for frogs, crustaceans, mollusks, and other food items. Cattail-dominated marshes are also expected to support a resident muskrat population.

- Abandoned Field

- Vegetation - Abandoned fields are generally cropland or grazing land on which human activity has been discontinued for several years. The dominant plant growth form in this type in the study area is herbaceous, composed of such species as goldenrod (Solidago sp.), old field cinquefoil (Potentilla simplex), wild sarsaparilla (Aralia nudicaulis) and bracken fern (Pteridium aquilinum). Other species such as black-eyed susan (Rudbeckia hirta), aster (Aster divaricatus) and Canada mayflower were also observed, although in lower numbers. Also present were scattered saplings and young shrubs of species such as cottonwood, smooth sumac (Rhus glabra), sweet fern (Comptonia peregrina), and bird cherry (Prunus pensylvanica), their density depending upon the period of time since abandonment. A total of 45 species of shrubs and herbs were observed in this type. This vegetative community is unstable and may, over a period of 15 to 20 years, be replaced by shrubland, the next successional stage, and eventually by the mixed forest type.

- Herpetofauna - The abandoned field habitats of the Millers R.O.W. were sampled for herpetofauna at the same time as the bird transects, from June 15 through 19, 1982. The only species observed in the abandoned field habitat was the American toad.

- Avifauna - One transect was sampled through the abandoned field habitat between June 15 and 19, as described in the methods, between 06:06 and 07:56 EDT, during periods with no high wind or rain. Clouds and light fog were encountered on one day, however these factors were not accompanied by rain or wind, and did not limit the visibility or audibility of nearby birds. Bird activity levels were not reduced in the judgment of the observer.

  Those species found to have the highest densities were: common yellowthroat, rufous-sided towhee, gray catbird, red-eyed vireo, and song sparrow.

Those species observed which were judged to be most typical of this habitat included: gray catbird, cedar waxwing, chestnut-sided warbler, common yellowthroat, indigo bunting, American goldfinch, rufous-sided towhee, and chipping sparrow.

In all, 26 species were observed in the abandoned field habitat of the Millers R.O.W..

- Mammals - Four small mammal species were trapped in this habitat type: short-tailed shrew, meadow vole, meadow jumping mouse, and woodland jumping mouse. The meadow vole and short-tailed shrew were the two most common species, representing 53% and 20% of all captures respectively. Only the meadow vole was captured in sufficient numbers to estimate density, which was approximately 29.8/ha. Numbers caught and density estimates for the above species are presented in Terrestrial Ecology Appendix Section 6.34.2. Both species of jumping mice were captured in this type due to the wetness at one end of the study area. This habitat was also considered excellent for cottontails and white-tailed deer.

- Shrubland - In open areas that have remained undisturbed for periods of 15 to 20 years, the dominant plant growth form is woody, consisting of shrubs and young trees typical of early succession. The shrubland community in the study area contained a predominance of late sweet blueberry (Vaccinium angustifolium), trailing bramble (Rubus hispidus) and meadowsweet. Twelve other species occurred in fewer numbers throughout this type including gray birch (Betula populifolia), sheep laurel, red oak (Quercus borealis) and black cherry (Prunus serotina). Present in patches and scattered throughout the shrub growth were herbaceous species characteristic of abandoned fields such as poverty grass (Danthonia spicata), little blue stem (Andropogon virginicus), goldenrod and panic grass (Panicum sp.). A total of 25 species of shrubs and herbs were observed in this type. Being a later stage in plant succession than the abandoned field type, the rate of change in this type is slower; perhaps over a period of 50 to 60 years the shrubland type may succeed to mixed forest.

- Herpetofauna - The shrubland habitats of the Millers River R.O.W. were sampled for herpetofauna at the same time as the bird transects, from June 15 through 19, 1982. No herpetofauna were observed in this habitat.

- Avifauna - One transect was sampled along the edge of a shrub swamp between June 15 and 19, as described in the methods, between 05:48 and 08:18 EDT, during periods with no high wind or rain. Clouds and light fog were encountered on one day, however these factors were not accompanied by rain or wind, and did not limit the visibility or audibility of nearby birds. Bird activity levels were not reduced in the judgment of the observer. Those species having the highest densities were: rufous-sided towhee, Nashville warbler, black-capped chickadee, gray catbird, and veery.

  Several species were observed which are particularly typical of this habitat, including: eastern kingbird, great crested flycatcher, black-capped chickadee, gray catbird, brown thrasher, common yellowthroat, American goldfinch, rufous-sided towhee, field sparrow, white-throated sparrow, and Nashville, chestnut-sided, and prairie warblers.

  In all, 25 species were observed in the shrubland habitat of the Millers R.O.W.

- Mammals - Only two species of small mammals were trapped in this habitat; masked shrew and meadow vole. Both species indicate the relative immaturity of the vegetation and openness of the habitat. This habitat was considered ideal for cottontails and deer. Tracks of raccoon, deer and domestic dog were observed in this habitat during the winter study.

- Hardwood-Dominated Mixed Forest - The mixed forests occupy, by far, the largest acreage of any natural habitat type in the study area. The Hardwood- Dominated Mixed Forest type differs from the SoftwoodDominated Mixed Forest only in having a higher proportion of hardwood species in the tree layer. Both types are interspersed throughout the study area. The Hardwood-Dominated Mixed Forest type contains a tree layer dominated by red oak, red maple and white pine, with other species such as sugar maple (Acer saccharum), paper birch (Betula papyrifera) and white oak (Quercus alba)

occurring in fewer numbers. The shrub layer was dominated by saplings of red maple, sugar maple and red oak, and shrub species such as black cherry, hazelnut (Corylus americana), ironwood (Carpinus caroliniana) and maple-leaved viburnum (Viburnum acerifolium) were scattered throughout the shrub layer in fewer numbers. The predominant species in the herbaceous layer were New York fern (Dryopteris noveboracensis), false Solomon's seal (Smilacina racemosa), Canada mayflower and starflower (Trientalis borealis). In addition to these species, fewer numbers of other woodland herbs were found including wild sarsaparilla, crested wood fern (Dryopteris cristata) and hog peanut (Amphicarpa bracteata). There was a total of 42 species observed in this type. The mixed forest type is a climax community in this area, and, as the species composition of the shrub layer indicates, is in a stable, self-perpetuating state.

- Herpetofauna - The hardwood-dominated mixed forests of the Millers R.O.W. were sampled for herpetofauna at the same time as the bird transects, from June 15 through 19, 1982. The only species noted was the gray treefrog (Hyla versicolor), calling occasionally from the trees.

- Avifauna - One transect was sampled through a hardwood-dominated mixed forest between June 15 and 19, as described in the methods (Terrestrial Ecology Appendix Section 6.34.2) between 06:02 and 07:38 EDT, during periods with no high wind or rain. Clouds and light fog were encountered on one day, however these factors were not accompanied by rain or wind, and did not limit the visibility or audibility of nearby birds. Bird activity levels were not reduced in the judgment of the observer.

  Those species found to have the highest densities were: great crested flycatcher, red-eyed vireo, ovenbird, and black-capped chickadee.

  One species which was observed is of special concern in Massachusetts: the mourning warbler, listed as a state local species. The bird was heard singing from a wet, shrub-swamp/forest edge and was most likely passing through the area on its way to its breeding range further north.

  Several species were observed which are highly dependent on this type of habitat including:

eastern wood pewee, wood thrush, red-eyed vireo, black-and-white and black-throated green warblers, ovenbird, mourning warbler, scarlet tanager and rose-breasted grosbeak.

In all, 20 species were observed in the hardwood-dominated mixed forests of the Millers R.O.W..

- Mammals - The eastern chipmunk and white-footed mouse were the only two species trapped in this habitat, representing 17% and 83% of all captures respectively. Only the white-footed mouse was captured in sufficient numbers to determine density, which was estimated to be 4.3/ha. Since many of the trees were mature, with a large number of natural cavities, this habitat was considered ideal for gray squirrels and raccoons. Tracks of both species were common during the winter survey. In those portions of the forest where the canopy was more open, tree seedlings and saplings provided abundant deer food.

- Softwood-Dominated Mixed Forest - The Softwood-Dominated Mixed Forest type differs from the Hardwood-Dominated Mixed Forest only in having a higher proportion of softwood species in the tree layer. The dominant tree species in this type were white pine and hemlock (Tsuga canadensis), with red maple, red oak, and black cherry occurring in fewer numbers. In the shrub layer the predominant species were late sweet blueberry, wintergreen (Gaultheria procumbens), and saplings of red maple and red oak. Occurring throughout this layer in fewer numbers were 22 other species including sheep laurel, huckleberry (Gaylussacia sp.), serviceberry (Amelanchier laevis) and witch hazel (Hamamelis virginiana). The herbaceous layer was dominated by starflower, Canada mayflower and sedge. Other species that were observed in lower numbers included ground pine (Lycopodium obscurum), hay-scented fern (Dennstaedtia punctilobula), wild sarsaparilla and upland sedge (Carex pensylvanica). A total of 52 species were observed in this type. As with the preceding community, the Softwood-Dominated Mixed Forest is a stable, self-perpetuating climax community in this area.

- Herpetofauna - The softwood-dominated mixed forests of the Millers R.O.W. were sampled for herpetofauna at the same time as the bird transects, from June 15 through 19, 1982. The

only species observed in the softwood-dominated mixed forest was the wood frog (Rana sylvatica), which was often seen foraging on the forest floor.

- Avifauna - One transect was sampled along the saddle north of Quabbin Reservoir, through Softwood- Dominated Mixed Forest. This sampling occurred between June 15 and 19, as described in the methods between 05:58 and 08:51 EDT, during periods with no high wind or rain. Clouds and light fog were encountered on one day, however these factors were not accompanied by rain or wind, and did not limit the visibility or audibility of nearby birds. Bird activity levels were not reduced in the judgment of the observer.

  Those species found to have the highest densities were: yellow-rumped and blackburnian warblers, brown-headed cowbird, American robin and purple finch. The brown-headed cowbird and American robin do not typically nest in this habitat type, and those observed were most likely transients. Several species were observed which are particularly typical of this habitat, including: eastern wood pewee, white-and red breasted nuthatches, hermit thrush, black-and-white, yellow-rumped, and blackburnian warblers, ovenbird, purple finch, rufous-sided towhee, and white-throated sparrow.

  In all, 29 species were observed in the softwood-dominated mixed forests of the Millers R.O.W..

- Mammals - White-footed mice were the most common species in this forest type with 75% of all captures and an estimated density of 4.6/ha. Meadow voles were the only other species caught and were restricted to those portions of the forest where the canopy was more open and herbaceous plant species had become established. Tracks of gray squirrels were observed on the study site during the winter survey, although red squirrels are more characteristic of this habitat type. Tracks of white-tailed deer were very common in this habitat during the winter survey. Dense stands of softwoods provide suitable winter cover for deer when the more preferred lowland types (e.g., conifer swamps) are not available.

- Threatened and Endangered Species - The spoilpile site southeast of Fairview Hill in New Salem, lies close to a recently verified occurrence of the common loon, a

species listed as state rare (Massachusetts Natural Heritage program, 1982). The mourning warbler, listed as state local, was observed in the vicinity of the spoilpile site near the junction of Route 2/202 and Athol Road in Athol.

- Selection of Indicator Species - From the inventory and analysis of baseline conditions presented in Section 6.34.1, indicator species of plants, herpetofauna, birds and mammals were selected for the Millers-Quabbin Tunnel R.O.W.. The term "indicator species" as applied in this report denotes (1) species representative of R.O.W. habitats, and (2) species sensitive to the kinds of perturbations that may result from development of the Millers-Quabbin Tunnel R.O.W..

  The group of species selected is representative of the trophic levels and habitats within the study area and within potential project impact areas and will be used to assess impacts of water supply development on these habitats. These species are listed in Table 6.34-1.

  The indicator species were selected on the basis of seven criteria; these criteria and the selection process are presented in the report "Task 4: Indicator Species Selection".

II. Future Conditions Without Alternative - Available information on land use and population to the year 2020 is very limited and the following analysis is the best possible given the limited data base. Based on the areawide 208 planning study (1977) population is expected to increase very slowly in the towns in the vicinity of the R.O.W. and changes in land use patterns and cover types will be minor. Future conditions in these areas, therefore, will be influenced primarily by natural plant community development processes. Because structural and compositional changes in plant communities occur relatively slowly, the differences in site vegetation and wildlife use between the three time periods considered below will be very slight.

- 1990 - The R.O.W. communities observed at the three spoil pile locations in the study area include shallow-marsh, abandoned field, shrubland, hardwood-dominated mixed forest and softwood-dominated mixed forest. The development pattern of the regional vegetation complex is one which culminates in a climax plant community dominated by oaks and pine. Due to the close functional and structural relation- ship of the R.O.W. vegetation to the regional complex, the

TABLE 6.34-1. INDICATOR SPECIES SELECTED FOR THE MILLERS-QUABBIN TUNNEL R.O.W. ASSESSMENT.

PLANTS	SCIENTIFIC NAME	HABITAT TYPE	TROPHIC LEVEL
Red oak	Quercus borealis	Softwood forest Hardwood forest	Primary producer
Beech	Fagus grandifolia	Hardwood forest	Primary producer
White pine	Pinus strobus	Softwood forest	Primary producer
Green ash	Fraxinus subintegerima	Bottomland forest	Primary producer
Sensitive fern	Onoclea sensibilis	Wet meadow	Primary producer
Blue-joint grass	Calamagrostis canadensis	Shallow marsh	Primary producer
Water naiad	Najas flexilis	Shallow marsh	Primary producer
Sweetflag	Acorus calamus	Shallow marsh	Primary producer
Rose pogonia	Pogonia ophioglossoides	Bog	Primary producer
Speckled alder	Alnus rugosa	Shrub swamp	Primary producer
Meadowsweet	Spiraea latifolia	Abandoned field	Primary producer
Gray birch	Betula populifolia	Shrubland	Primary producer
WILDLIFE			
American crow	Corvus brachyrhynchos	All habitats listed above	Detritivor
White-throated sparrow	Zonotrichia albicollis	Softwood forest Shrubland	Herbivore
Swamp sparrow	Melospiza georgiana	Shallow marsh Shrub swamp	Herbivore
White-breasted nuthatch	Sitta carolinensis	Hardwood forest Bottomland forest	Primary carnivore

TABLE 6.34-1. (Continued)

WILDLIFE	SCIENTIFIC NAME	HABITAT TYPE	TROPHIC LEVEL
Chestnut-sided warbler	Dendroica pensylvanica	Abandoned field Shrubland	Primary carnivore
Red-tailed hawk	Buteo jamaicensis	Hardwood Forest Softwood forest Bottomland forest Shrub swamp Abandoned field Shrubland	Higher order carnivore
Barred owl	Strix varia	Softwood forest	Higher order carnivore
Great Blue Heron	Ardea herodias	Bottomland forest Wet meadow Shallow marsh Bog, Shrub swamp	Higher order carnivore
Gray squirrel	Sciurus carolinensis	Hardwood forest Bottomland forest	Herbivore
Meadow vole	Microtus pennsylvanicus	Wet meadow Bog, Shrub swamp Abandoned field Shrubland	Herbivore
Muskrat	Ondatra zibethica	Shallow marsh	Herbivore
Short-tailed shrew	Blarina brevicauda	All habitats listed under "Plants" except Shallow marsh, Bog	Primary carnivore
Pickerel frog	Rana palustris	Shallow marsh, Bog	Primary carnivore
Black rat snake	Elaphe obsoleta	Abandoned field Shrubland	Higher order carnivore

sequences and rates of maturation can be assumed to be the same. The time required for a type such as abandoned field to mature to a climax forest may be a hundred years. A shrubland is a later developmental stage and will mature in a somewhat shorter period. Wildife species composition will shift as the plant community matures, from open land species to those that favor woodlands. In a similar manner, shallow marsh will most likely become dominated by plant species typical of the shrub swamp type, with accompanying changes in wildlife species. Mixed forests, on the other hand, which are already at or near the climax stage will change very slowly. Given the minor population and land use changes expected, conditions in 1990 will differ only slightly from existing conditions. The minor changes that occur will be due to a slight maturation of the abandoned field, shrubland and shallow marsh type.

- 2000 - By 2000, the shallow marsh and abandoned field types will be succeeded by woody species typical of shrub swamp and shrubland respectively. This will provide habitat for wildlife species characteristic of the later successional stages. The shrubland community will mature due to the growth of saplings and shrubs; however, wildlife species composition will remain typical of the species found in shrubland. It is unlikely that the saplings will be sufficiently abundant by 2000 to alter community structure so as to affect wildlife species composition. The mixed forest types will change relatively little as a result of plant community development. With these minor exceptions, conditions by the year 2000 will not be substantially different from existing conditions.

- 2020 - By 2020 saplings of mixed forest tree species may become established in the shrubland growth that will have become predominant in the abandoned field by the year 2000. At this stage, the community will be a young mixed forest and wildlife typically found in such habitats will also begin to utilize this type. Similarly, the shrubland type will have succeeded to young mixed upland forest with concomitant shifts in wildlife species composition to those species characteristic of the later successional stages. Since wetlands mature more slowly, it is unlikely that saplings typical of wooded swamp communities will have become established in sufficient numbers to alter community structure and the shrub swamps will continue to predominate in former shallow marsh areas by 2020.

  The mixed forest type will remain essentially unchanged although tree growth will continue. If

crown development increases shading to the understory and alters the species composition and density of shrubs and herbs, wildlife species composition may shift from ground nesting species to those favoring large trees for nesting and/or feeding.

Except for these natural development processes, conditions by the year 2020 will not be substantially different from existing conditions.

6.34.2 Future Conditions With Alternative

Future conditions with the project are assessed both for the short term construction period and long term. As was the case for the Northfield-Quabbin R.O.W., construction period impacts address immediate effects of vegetation removal on plant and wildlife communities, indicator species and species of special interest (Impacts to Existing Conditions). Assessment of construction impacts also includes effects such as disturbance, noise and soil erosion (Construction Impacts). Future conditions address impacts on baseline conditions projected to three future time periods, and consider changes in communities and indicator species brought about by the processes of stabilization and regrowth at each of the three impacted areas along the R.O.W.. Short and long term project impacts on indicator species utilizing potentially affected habitats are summarized by impact category and habitat in the matrix in Table 6.34-2.

I. Short-term Construction Period

- Impacts to Existing Conditions

  At each of the three impact areas along the R.O.W., permanent and temporary features including spoil piles, roads, and construction staging areas will result in the permanent loss and temporary disturbance of vegetative cover. The regrowth at each of the areas will consist of earlier, less stable successional stages than presently exist (See II. Long-Term). The effect of this cover change will be assessed from the standpoint of impact to the vegetative and wildlife communities on the Millers-Quabbin R.O.W. and impact to the plant and animal indicator species selected to represent the communities in the vicinity of each of the three impact areas.

  - First Spoil Pile (Millers River) - At the first spoil pile location, just upstream of the intake structure on the Millers River, disposal of the tunnel spoil, construction laydown areas, and other facilities will

TABLE 6.34-2. SUMMARY OF IMPACTS OF THE MILLERS-QUABBIN R.O.W. ON TERRESTRIAL PLANT AND WILDLIFE INDICATOR SPECIES.

	HABITAT TYPE								
Impact Categories:	Hard-wood Dominated Mixed Forest	Soft-wood Dominated Mixed Forest	Bottom Land Forest	Wet Meadow	Shallow Marsh	Bog	Shrub Swamp	Abondoned Field	Shrub Land
Erosion	X	X							
Water Quality									
Water Quantity					X		X		
Water Level					X		X		
Habitat Loss/ Change	X	X			X		X		
Displacement/ Disruption	X	X			X		X		
Entrainment/ Impingement									
Vegetation Composition Changes	X	X			X		X		

remove 6.5 acres of primarily mixed forest; an additional acre will be temporarily disturbed.

The plant indicator species potentially affected by these activities include red oak and white pine. The wildlife indicator species potentially affected by habitat loss or change, and temporary displacement or disruption include a detritivore (American crow), an herbivore (gray squirrel), two primary carnivores (white-breasted nuthatch and short-tailed shrew) and a higher order carnivore (red-tailed hawk) (Table 6.34-1). All of the above indicator species utilize the mixed forest habitat type to fulfill feeding and breeding requirements.

Hundreds of acres of the mixed hardwood-softwood forest type occur in the vicinity of the R.O.W. The loss of this small amount of acreage will have little if any affect on the populations of red oak and white pine and the surrounding vegetative complex. The impacts of loss of habitat necessary to fulfill life cycle requirements are expected to be within the range of tolerance of plant and wildlife indicator species and communities since other stands of mixed fores are abundant and may also be expected to support populations of these indicator species. Displacement and disruption impacts will be temporary, occurring only during the construction period.

- Second Spoil Pile (Athol Road) - The second spoil pile location, on the east side of Athol Road, is also vegetated primarily by mixed upland forest, although an abandoned field, a 4 acre shrub swamp and an 11 acre marsh also occur within the potential impact area. The upland portion of the potential impact area is in the headwaters of the two wetland areas. The spoil pile and other permanent and temporary facilities will remove 14.25 acres, primarily in the upland forest areas. This may have a significant adverse impact on the hydrologic budget of the wetlands, reducing the moisture available and resulting in a shift in plant and wildlife species to those found more typically in dryer shrubland communities.

  Plant indicator species affected by removal of mixed forest are red oak and white pine; wildlife indicator species potentially affected by habitat loss/change are the same species discussed for the first spoil pile. The mixed hardwood-softwood cover type is well represented in the vicinity of each of the spoil piles and along the R.O.W. Based on its commonness and the

relatively small area affected, removal of mixed forest will have an insubstantial impact on the species populations of the two plant indicator species and on the surrounding vegetative complex. As was true at the first spoil pile location, the effect of the loss of mixed forest habitat on the five wildlife indicator species for this type will also be within their ranges of tolerance since other stands of mixed forest may also be expected to provide habitat. Impacts to the mourning warbler are unlikely because there is no evidence of it nesting in the vicinity of this spoil pile.

Some of the construction activities would occur on the margins of the wetlands which could produce temporary secondary effects resulting from site disturbance and noise; however the proper controls should be applied to reduce noise levels and erosion.

- Third Spoil Pile (Fairview Hill) - The third spoil pile location, east of Fairview Hill, is vegetated primarily by hardwood, softwood, and mixed upland forest. Two alternative tunnel outlet structures have been proposed. For the first alternative, the direct tunnel outlet, the disposal of tunnel spoil and other permanent and temporary facilities will remove 23.5 acres and temporarily disturb another 2 acres. The second alternative, the deep channel outlet, will remove 53 acres and temporarily disturb another 2 acres.

The plant and wildlife indicator species discussed in relation to the first and second spoil piles are the same species expected to be affected at the third spoil pile. The mixed upland forest type is also well represented in the vicinity of this spoil pile and along the R.O.W. Although the impact of the second alternative is twice that of the first, the impacts of habitat loss on the indicator species populations and plant and wildlife communities are expected to be within their ranges of tolerance.

A 10 acre shrub swamp and North and South Spectacle Pond exist in the vicinity of the third spoil pile, however, neither the wetland nor the ponds are expected to be affected by either permanent or temporary structures provided that standard erosion control practices are implemented. The common loon, known to nest within Quabbin Reservoir, will not be affected by impacts at the third spoil pile location.

- Construction Impacts

Aside from the immediate effect of actual removal, discussed under "Impacts to Existing Conditions", the only significant construction impact on vegetation will be erosion. If uncontrolled during and after construction, soil loss from the impacted areas and immediately adjacent areas would bring about a loss in soil fertility, reducing the rate of regrowth and affecting long term plant production. Soil transported to and deposited in other locations would have localized adverse affects on low growing vegetation in those plant communities. Both short and long term erosion control and revegetation measures should be developed in order to reduce this impact to an absolute minimum (Section 6.34.4).

The potential short-term impacts of the construction activities on wildlife include disturbance due to noise and the presence of humans, temporary loss of some habitats, direct mortality associated with land clearing and filling, and the effects of air emissions from the construction equipment.

Land clearing and construction activity in the project area is expected to generate noise in the 70-98 dB(A) range. Generally, impacts of noise on wildlife fall into three categories (Memphis State University, 1971): 1) interference with intra- and interspecific communication, 2) injury to the hearing apparatus, and 3) effects on the animal's neuro-endocrine system similar to stress. Most vertebrate species would instinctively move away from noise sources so as to avoid the latter two effects. Interference with communication primarily involves the masking of species-specific calls or other vocalizations used in courtship, territorial defense, parent-young interactions, or predator evasion. Song birds (e.g., wood warblers, thrushes, finches) are the primary group which would be affected in the project area. Many amphibians (frogs and toads) also use auditory signals for communication, although this normally occurs in the evening or at night when construction activity will have ceased.

The land clearing and filling required for the project will result in the unavoidable mortality of a certain fraction of the wildlife populations residing in the area. Highly mobile species, including all birds and large mammals, will leave the area once the construction activities commence. Other species, such as small mammals, reptiles, and terrestrial amphibians will, however, seek refuge in underground burrows or

other sheltered areas and perish. If construction takes place during the breeding season for birds (primarily spring and early summer), there will also be the unavoidable loss of all nests with eggs and young in the con- struction areas. Similarly, the litters of all breeding mammals will be lost.

Impacts associated with fugitive air emissions, such as dust and exhaust fumes from the construction equipment, will be very localized. As most vertebrate species will seek cover away from the construction activities, this impact is expected to be minimal. Insects and other invertebrates are more likely to be directly impacted, resulting in some secondary effect on wildlife higher in the food web which depend on them for food. As the area involved is relatively small, this impact is not considered significant.

II. Long-Term - This section assesses long term impacts of the project on the communities of plants and animals, and the indicator species occurring at the three impact areas. Following removal of the vegetative cover at each of the three areas, establishment of earlier, less stable successional stages will occur. These communities will mature over the three time periods considered below, following the same pattern as the regional complex which culminates in a climax community, but at a faster rate than the established communities now existing.

This difference in successional rate between future conditions with and without the project constitutes the major impact, except where species of special concern are involved. Whereas most of the indicator species now present may be expected to reoccur when the vegetation at the impact areas has attained a certain developmental stage, the conditions appropriate for species of special interest may or may not appear again at the revegetated and recolonized site. Differences in site vegetation and wildlife use between the three time periods with the project will be greater than the differences without the project.

- 1990 - Immediately following construction activities a seeding of grasses and legumes will be established for erosion control and site stabili- zation in all disturbed areas. Depending upon soil characteristics, the initial seeding on the upland sites can be expected to be supplemented by a natural cover of various forbs and grasses by 1990.

  Former wetland sites would be colonized by hydrophytic grasses, rushes and sedges. The indicator species

meadowsweet, blue-joint grass and sensitive fern would likely be part of these early successional stages.

Among the wildlife initially colonizing these early successional stages will be the meadow vole, short-tailed shrew, and chestnut-sided warbler, all indicator species. Without standing water, these new habitats are not expected to be of any substantive value to the great blue heron, another indicator species. Crows will, however, readily utilize these areas for scavenging.

- 2000 - After the inital several years of site stabilization and early succession, the plant communities in the disturbed areas can be expected to be colonized by "pioneer" shrubs and saplings characteristic of early, unstable successional stages. Such early established woody species would include sweet fern, trembling aspen, gray birch (an indicator species) and pin cherry; on sites formerly forested, root suckers and sprouts would in addition, give rise to saplings of overstory species such as red oak (an indicator species). On moist soils at former wetland sites highbush blueberry and speckled alder (an indicator species) would be expected to become established. Over time, the shrubs and saplings will predominate as the impacted areas succeed from an herb dominated community to a shrubland. Depending on their height and steepness, plant community succession on the spoil piles may occur much more slowly due to the steepness and suboptimal physical and chemical soil conditions; moreover, the slope conditions could prevent placement of organic soils, liming and fertilizing to aid plant growth.

The newly established shrubland communities will provide habitat for several of the wildlife indicator species: short-tailed shrew, meadow vole, American crow, chestnut-sided warbler, red-tailed hawk, and black rat snake. Meadow vole populations will be relatively low since this habitat is rapidly becoming too mature for this species. However, short-tailed shrews as well as more woodland species like the white-footed mouse will be common. The shrub-thicket habitat will also provide ideal cover for nesting chestnut-sided warblers and other old- field and shrubland species such as the white-eyed vireo, blue-winged warbler, common yellowthroat, prairie warbler, and song sparrow. Both crows and the red-tailed hawk will use this habitat for feed- ing and perching. As the vegetation continues to mature, its suitability for the black rat snake, a primarily woodland species, will similarly increase.

- 2020 - After a period of more than thirty years have elapsed since the construction phase, the shrub/sapling community that has become established on the upland sites at the impacted areas will have a component of young tree species characteristic of the oak-pine climax forest. Among these species red oak and white pine, both indicator species, would be expected to predominate as the community develops, along with smaller proportions of white oak, hemlock and red maple. Former wetland sites would contain high proportions of species characteristic of wooded swamps such as red maple, hemlock and black spruce. Over time, most of the disturbed areas will succeed to the climax forest stage, having characteristics similar to the same communities in undisturbed areas. As noted above, plant communities on the spoil piles will develop much more slowly due to suboptimal physical and chemical soil conditions, perhaps never succeeding to a true climax stage.

  As the vegetation matures towards a young forest habitat, species such as the meadow vole and chestnut-sided warbler will disappear. White-footed mice will be common, along with several new species of breeding birds including the gray catbird, brown thrasher, and rufous-sided towhee. White-throated sparrows (an indicator species) will be abundant in those brushy areas dominated by softwoods. Some mature forest bird species, like the black-capped chickadee and blue jay, may also begin breeding in this habitat.

6.34.3 Summary of Significant Impacts

Potentially significant impacts to the vegetation and wildlife of the Millers-Quabbin R.O.W. are those resulting from indirect effects of construction activities in the adjacent upland on the surface water hydrology of the marsh and shrub swamp at the Athol spoil pile location. The upland is a recharge area for these wetlands and a reduction in water budget would probably reduce the amount of moisture available and cause a shift in plant and wildlife community composition to species more typically found in mesic shrublands.

I. Measures of Significance - The acreage involved at each of the three impact areas in the Millers-Quabbin R.O.W. for spoil piles, roads, construction laydown areas, and other temporary and permanent facilities was determined. The vegetation and wildlife at each of the sites was identified and their uniqueness relative to the surrounding communities determined. Indicator species representative of each community which will respond to perturbations

resulting from the project were selected (see "Task 4: Indicator Species Selection"). The uniqueness of the impacted plant and wildlife communities, presence of species of special concern, and sensitivity of these biota and any indicator species to project impacts formed the basis for judging the relative significance of the impacts.

II. Significant Impacts - The project will indirectly impact the marsh and shrub swamp at the Athol spoil pile by destroying or disturbing a significant portion of the recharge area in the adjacent upland.

6.34.4 Mitigation/Enhancement Measures

1. Erosion control and revegetation should be done during, and following, construction and site stabilization.

2. Construction activities should be timed to begin before the spring and early summer breeding period of most wildlife species, so that impacts to breeding wildlife are minimized or eliminated.

3. An adequate buffer between project facilities and wetlands should be provided for their protection.

4. The Athol spoil pile should be relocated to avoid impacting the marsh and shrub swamp, as well as the upland recharge area.

6.35 TERRESTRIAL ECOLOGY OF THE MILLERS RIVER FLOODPLAIN AND TULLY RIVER FLOODPLAIN BETWEEN ATHOL AND TULLY LAKE

The assessment of the vegetation, herpetofauna, birds and mammals for the study area of the Millers River Floodplain is presented in Section 6.33. The compounding effect of a transfer from Tully reservoir on the Millers River Floodplain is assessed in Section 6.35.2. An assessment of the vegetation, herpetofauna, birds and mammals of the Tully River Floodplain between Athol and Tully Lake was conducted (Figure 6.33-1). This entire section of the Tully River was included in the assessment because it could be affected by a flow reduction of more than 5% as a result of a transfer from Tully Lake. Based upon a 50 year record the average annual minimum and maximum flows in the Tully River are 2.2 and 651.6 cfs respectively. Flow variation within any given year can, of course, exceed this range.

6.35.1 Baseline Conditions

Assessments of the existing baseline, and baseline conditions projected to 1990, 2000 and 2020 without the project were made. Descriptions of study methods, species lists and quantitative data are presented in Terrestrial Ecology Appendix Section 6.35.2.

I. Existing Conditions - In the following sections previous investigations applicable to the Tully River Floodplain are presented by groups of biota. The results of field investigations conducted in 1982 are discussed by vegetative community.

- Literature Surveys
  - Vegetation
    - Regional Vegetation - The vegetation of the Tully River Floodplain is part of the regional vegetation discussed in Section 6.33.1.
    - Floodplain Vegetation - No previous investigations of the floodplain vegetation of the Tully River are known to have been conducted.
  - Wildlife - No previous investigations of the herpetofauna, birds or mammals of the Tully River Floodplain are known to have been conducted, however, existing information for the Millers Floodplain (Section 6.33.1 I) applies also to the Tully Floodplain.

- Field Surveys - In the following subsections, the results of field investigations conducted at locations representative of the floodplain and wetland habitats in the study area are discussed for herpetofauna, avifauna and mammals. Field investigations for vegetation were not conducted because the types occurring along the Tully River Floodplain are also represented in the Millers River Floodplain where field studies were conducted in 1982. The descriptions for these types in Section 6.33.1, therefore, apply to the floodplain and wetland plant communities of both the Millers and Tully Rivers. The locations of transects where the faunal studies were conducted are shown in Figure 6.33-1. The groups of biota are presented beginning with the earliest plant successional stage and most primitive wildlife group. Complete species lists and data are presented in Terrestrial Ecology Appendix Section 6.35.2. In general, the wildlife found to be present in the floodplain and wetland types of the study area were representative of the fauna of central New England. The types occurring along the Tully River Floodplain are shallow marsh, shrub swamp and bottomland forest.

  - Shallow Marsh

- Herpetofauna - Searches for reptiles and amphibians were not conducted in this habitat because of its close similarity to the shallow marsh sampled in the floodplain of the Millers River. The results of investigations in that marsh are considered representative for the shallow marsh habitat in the Tully River floodplain.

- Avifauna - Bird surveys were not conducted in the Tully River shallow marsh type because results of investigations in the shallow marsh type in the Millers River floodplain are considered representative for this habitat in the Tully River floodplain.

- Mammals - This habitat was not trapped because of its wetness. Based on the results of trapping in nearby habitats, one could expect white-footed mice, eastern chipmunks, and perhaps woodland jumping mice to be common along the marsh/woodland edges. Muskrats will be found in those marshes which provide ample food, especially cattails. Raccoons will also forage along its shoreline.

- Shrub Swamp

- Herpetofauna - Searches were conducted at the same time as the bird transects, however, herpetofauna were not observed. The shrub swamp has a surface water connection to the river, and riverine fish may produce a high predation factor on aquatic herpetofauna.

- Avifauna - One transect was placed near the search location mentioned above. The Tully River shrub swamp was one of the most productive areas encountered during this study. It lies west of the river, across from the Athol landfill, and northeast of sand and gravel pits. The transect was sampled during May 25-28, between 06:03 and 07:56 EDT. As mentioned above, overcast and foggy weather was encountered during this sampling, but the observations of nearby birds within this habitat were not hampered, since sound reduction due to wind or rain was not a factor at any time and the birds were found to be normally vocal and active during each sampling period.

The five species having the highest densities in this habitat were found to be: rough-winged swallow, alder flycatcher, American crow, common yellow-throat, and American goldfinch.

Birds of special concern seen on transect were: great blue heron (rare), and swainson's thrush (local). Although the former species was undoubtedly utilizing this habitat for breeding purposes, the swainson's thrush was most likely a late migrant; it was not observed singing more than once, and was not encountered on more than one day. This species is habitually a late and lingering migrant.

In addition to the transect observations, casual notes were made of species during other phases of the work: a veery nest was found adjacent to the transect, and a virginia rail was heard calling on several days during the field work but was silent during the actual transect sampling. In all, 33 species were noted on transect, with the rail sighting contributing to a total of 34 for the habitat.

Species observed, which are particularly dependent on the river or on the shrub swamp were: great blue heron, mallard, virginia rail,

rough-winged swallow, northern waterthrush and swamp sparrow.

- Mammals - Only one species, the meadow jumping mouse, was trapped in this habitat. This species was caught previously in the area of shrub swamp where sedge predominated. The density of jumping mice was estimated to be 33.9/ha. Fox tracks (species unknown) were observed along the edge of this habitat during the winter survey. Although none were observed, raccoons also typically forage in this wetland habitat type.

- Bottomland Forest

- Herpetofauna - The dates for the field surveys were the same as those mentioned above for other habitats, May 25-28.

  The species found were spring peepers (Hyla crucifer) and a milk snake (Lampropeltis triangulum), although the latter was probably utilizing nearby upland habitats more fully than the bottomland forest.

- Avifauna - One transect was sampled in bottomland forest for avifauna along the Tully River. The times were interspersed among those for the other habitats, and ranged from 05:39 to 08:22 EDT, with weather conditions being the same as those described above.

  The species observed which had the highest computed densities were: black-capped chickadee, gray catbird, yellow warbler, red-winged blackbird and common grackle.

  Species highly dependent on this habitat were: green heron, least flycatcher, tree swallow and Louisiana waterthrush.

  In all, 25 species were observed in the bottomland forests of the study area.

- Mammals - Only two species were caught in this habitat type along the Tully River, the eastern chipmunk and the woodland jumping mouse. The density of the woodland jumping mouse was estimated at approximately 3.8 mice/ha, but there were too few captures to estimate densities for the chipmunk. Evidence of raccoon and red squirrel activity was very common in this type. A "slide" apparently used by a river otter was

also observed along the river bank during the June field investigations. Tracks of gray squirrel, beaver, white-footed mouse, domestic dog, fox (species unknown), raccoon, and river otter were observed during the winter survey.

- Threatened and Endangered Species - Two species of concern were observed within the study area of the Tully River Floodplain, the great blue heron (state rare) and swainson's thrush (state local).

- Selection of Indicator Species - Because of the close similarity between habitats and baseline conditions in the Tully River Floodplain and those in the floodplain of the Millers River, and given that the kinds of impacts will be similar, the list of indicator species selected for the Millers floodplain will also be used to represent the Tully. The list of indicator species used in the assessment of impacts is presented in the report "Task 4: Indicator Species Selection".

II. Future Conditions Without Alternative - As is true for the Millers River, population in the towns bordering the Tully River is expected to increase very slowly based on the 208 planning study (1977). Associated changes in land use patterns and cover types will also be minor, and future characteristics of the vegetatively defined floodplain will be primarily the result of natural plant community development processes. Changes in wetland and floodplain plant communities occur very slowly, and differences in vegetation and wildlife use between the three time periods are expected to be very slight. Since the vegetative types occurring along the Tully River Floodplain also occur in the Millers River Floodplain the projections of future conditions at the three time periods for the Millers River in Section 6.33.1 II also apply to the Tully River.

6.35.2 Future Conditions With Alternative

Future conditions with this alternative are assessed for the construction period and three future time periods, in the same manner as for the Millers River. Construction period and long term project impacts on indicator species utilizing potentially affected habitats along the Tully River floodplain will be similar to those anticipated for the Millers floodplain. These impacts are summerized by impact category and habitat in the matrix in Table 6.33-2.

I. Short-term Construction Period - A drop shaft constructed on the bank of Tully Lake and other facilities will involve removal of 2.5 acres of predominantly mixed upland forest, and temporary disturbance of an additional acre. Hundreds of acres of this vegetative type occur in

the vicinity of Tully Lake and the Tully River floodplain, and impacts to plant and wildlife indicator species, populations and communities are expected to be within their ranges of tolerance. Vegetation removal from the small, localized area of the drop shaft will be a minor impact to the species populations and surrounding vegetation and wildlife communities.

II. Long Term - Changes in water level at a representative section of the Tully River Floodplain (Terrestrial Ecology Appendix Figure 6.35-1) with the proposed transfers were determined based on 40 year average flow data for April, May and June. The calculations demonstrated that the decrease in water level caused by the diversion (34 cfs) during April and May would be 2 inches, and that the lateral change on the floodplain would be approximately 2 feet. For the reasons discussed in Section 6.33.2 II, in relation to a similar change for the Millers River, this change will produce no observable affect on floodplain plant communities.

In June the flows will be sufficient for withdrawal of the maximum potential transfer for that month (25 cfs) approximately 21 percent of the time, while maintaining the 63 cfs minimum flow requirement. The calculations demonstrate that the decrease in water level due to the transfer will be approximately 2.5 inches resulting in a decrease of one foot in lateral flooding. At this point the water will be approximately 2 inches below the top of the channel, an insignificant change with respect to exposed littoral zone, because the banks are relatively steep and the channel well defined. For the 6 days per month the water will be at this level, there will be no observable affect on wetland or river channel vegetation or upon wildlife habitat. Any reduction in Tully River flow due to the proposed transfers will have no perceptible effect on water level in the Millers River, because Tully flow contributes only a very small percentage to the Millers flows.

Since changes in water quantity and quality are not expected to differ substantially from conditions predicted without the alternative, changes in the floodplain plant and animal communities for 1990, 2000 and 2020 will be as discussed in Section 6.33.1 II.

6.35.3 Summary of Significant Impacts

No significant short or long term impacts to floodplain, wetland or river channel plant or wildlife communities, indicator species or species of special interest are expected to occur as a result of the proposed transfer.

I. Measures of Significance - Existing water quality baselines were determined and projections with and without the project were made. Changes in water level relative to the floodplains and river channel due to the project were determined based on 40-year average flow data for April, May and June, the most important times of the year with respect to floodplain and river channel inundation requirements. Vegetation and wildlife were identified and their uniqueness relative to the surrounding communities determined. Indicator species representative of floodplain communities which will respond to water level and water quality changes were selected (see "Task 4: Indicator Species Selection"). The uniqueness of the plant and wildlife communities, presence of species of special concern, and sensitivity of these biota and any indicator species to changes in water level or quality were the measures used to judge the significance of project impacts.

II. Significant Impacts - There are no significant impact issues.

6.35.4 Mitigation/Enhancement Measures

1. Erosion control during construction.

2. Timing of construction activities to avoid the spring and early summer breeding period of most wildlife species.

3. Provision of an adequate buffer between project facilities, water bodies and wetlands.

6.36 TERRESTRIAL ECOLOGY OF THE TULLY-ATHOL TUNNEL R.O.W.

An assessment of the vegetation, herpetofauna, avifauna and mammals of the Tully-Athol Tunnel R.O.W. was conducted based on existing information and field investigations within the adjacent Millers-Quabbin Tunnel R.O.W. The assessment area included the entire R.O.W. from Tully Lake to the proposed transfer at Athol (Figure 6.34-1).

6.36.1 Baseline Conditions

Assessments of the existing baseline, and baseline conditions projected to 1990, 2000 and 2020 without the project were made.

I. Existing Conditions - In the following sections previous investigations applicable to the Tully-Athol Tunnel R.O.W. are presented by groups of biota.

- Literature Surveys
  - Vegetation
    - Regional Vegetation - The vegetation of the Tully-Athol Tunnel R.O.W. is part of the regional vegetation discussed for the Millers River in Section 6.33.1.
    - R.O.W. Vegetation - No previous investigations of the vegetation of the Tully-Athol Tunnel R.O.W. are known to have been conducted.
  - Wildlife - No previous investigations of the herpetofauna, birds or mammals of the Tully-Athol Tunnel R.O.W. are known to have been conducted, however existing information pertaining to the Millers-Quabbin Tunnel R.O.W. (Section 6.34.1 I) applies also to the Tully R.O.W.
- Field Surveys - There were no field investigations conducted by NAI because the types occurring along the Tully-Athol R.O.W. were also represented along the Millers-Quabbin R.O.W. where field studies were conducted in 1982. The descriptions for these types in Section 6.34.1, therefore, apply to the R.O.W. plant and wildlife communities of both the Millers-Quabbin R.O.W. and Tully-Athol R.O.W. The types found along the R.O.W. are mostly softwood and hardwood dominated mixed forest with a small amount of abandoned field and agricultural land.

- Threatened and Endangered Species - There are no threatened or endangered species of plants or wildlife known to occur within the study area of the Tully-Athol R.O.W. (Massachusetts Natural Heritage Program, 1982).

- Selection of Indicator Species - Because of the close similarity between habitats and baseline conditions along the Tully-Athol R.O.W. and those in the Millers-Quabbin R.O.W. and because the kinds of impacts will be similar, the list of indicator species selected for the Millers R.O.W. will also be used to represent the Tully. The list of indicator species used in the assessment of impacts is presented in the report "Task 4: Indicator Species Selection".

II. Future Conditions Without Alternative - As is true for the Millers River R.O.W., the population in the watershed bordering the Tully-Athol R.O.W. is expected to increase very slowly based on the 208 planning study (1977). Associated changes in land use patterns and cover types will also be minor, and future conditions will be primarily the result of natural plant community development processes. Since the vegetative types occurring along the Tully River R.O.W. also occur in the Millers River R.O.W. the projections of future conditions at the three time periods for the Millers River in Section 6.34.2 also apply to the Tully River.

6.36.2 Future Conditions With Alternative

Future conditions with this alternative are assessed for the construction period and 1990, 2000 and 2020 in the same manner as for the Millers River R.O.W. Construction period and long term project impacts on indicator species utilizing potentially affected habitats along the Tully-Athol R.O.W. are similar to these anticipated for the Millers-Quabbin R.O.W. These impacts are summarized by impact category and habitat in the matrix in Table 6.34-2.

I. Short-term Construction Period - Construction of the facilities for the Tully-Athol R.O.W. will involve removal of approximately 10.5 acres of mostly mixed upland forest. Based on the close similarity of the plant communities and wildlife habitats in this R.O.W. compared to those of the Millers-Quabbin R.O.W., construction impacts on indicator species and plant and wildlife communities will be as discussed in Section 6.34.2I. As was true for the Millers R.O.W., impacts are expected to be within the ranges of tolerance of indicator species and communities. Habitat removal from the small, localized area due to the project will result in an insubstantial impact to the populations

of indicator species and the surrounding vegetation and wildlife communities.

II. Long Term - Because of the close similarity of Tully-Athol R.O.W. plant communities and wildlife habitats to those of the Millers-Quabbin R.O.W., the general comments in Section 6.34.2-II pertaining to long term impacts, and specific comments discussing patterns of colonization by plants and wildlife during 1990, 2000 and 2020 will also apply to expected conditions in the Tully R.O.W..

6.36.3 Summary of Significant Impacts

No significant short or long term impacts to R.O.W. plant or wildlife communities or indicator species are expected as a result of the proposed transfer.

I. Measures of Significance - The acreage involved at the impact areas in the Tully-Athol R.O.W. for spoil piles, roads, construction laydown areas, and other temporary and permanent facilities was determined. The uniqueness of vegetation and wildlife likely to occur at each of the sites relative to the surrounding communities was determined. Indicator species representative of each community which will respond to perturbations resulting from the project were selected (see "Task 4: Indicator Species Selection"). The uniqueness of the impacted plant and wildlife communities, presence of species of special concern, and sensitivity of these biota and any indicator species to project impacts formed the basis for judging the relative significance of the impacts.

II. Significant Impacts - There are no significant impact issues.

6.36.4 Mitigation/Enhancement Measures

Erosion control and revegetation during construction and site stabilization should be instituted, particularly in the vicinity of wetlands and open water.

6.36.5 Terrestrial Ecology of the Connecticut River Floodplain

The assessment of the vegetation, herpetofauna, birds and mammals for the study area of the Connecticut River Floodplain is presented in Section 5.33. Any reduction in Millers River flow due to the proposed transfers will have no effect on water level in the Connecticut River because the safe yield model for Millers includes the maintenance of a 17,000 cfs minimum flow at Montague as one of the constraints.

6.37 AQUATIC ECOLOGY OF THE MILLERS RIVER

6.37.1 Baseline Conditions

I. Existing Conditions

- Macroinvertebrates

  - Previous Investigations - Benthic samples from immediately above Athol to Millers Falls, collected by the Massachusetts Division of Water Pollution Control (MWPC, 1973) contained pollution tolerant taxa only (i.e. Chronomidae, Oligochaeta, and Isopoda). The survey was made in 1965, when drought conditions prevailed and water quality was particularly poor. Some of the samples collected contained no living organisms at all.

    By 1969, some pollution intolerant benthic macroinvertebrate taxa had been collected by Godfrey (1970) indicating that conditions in the Millers River had improved somewhat since the 1965 survey. Sampling from Athol to Millers Falls, Godfrey (1970) reported 37 taxa (Aquatic Ecology Appendix Table 6.37.1-1), including such pollution intolerant groups as Plecoptera, Ephemeroptera and Trichoptera; benthic organism densities ranged from less than $10.3 m^{-2}$ in the vicinity of Millers Falls to over $2 \times 10^5 m^{-2}$ near Athol.

    A subsequent benthic survey, (MWPC, 1973) recorded 18 taxa from Athol downriver to Millers Falls, nominally, less than half the number reported by Godfrey (1970). Taxa were generally identified to family in the MWPC (1973) study; whereas most organisms were identified to genus in the Godfrey (1970) study. The dominant taxa collected (MWPC, 1973) included: Isopoda, Oligochaeta, Hirundinea, Heptagenidae, and Hydropsychidae. Upstream vs. downstream density trends were not readily apparent.

    Samples from the Millers River at Irving collected in 1978 (Bilger per comm.) indicated increased benthic diversity in this reach. Specifically, pollution intolerant stonefly taxa were observed.

  - Investigations in 1982 - More than two and a half times as many taxa were collected by NAI investigators in July and October of 1982, as had

been reported by Godfrey (1970) (Aquatic Ecology Appendix Table 6.37.2-3); the pollution intolerant order Trichoptera alone was represented by 26 taxa. Another seven intolerant taxa belonged to the order Plecoptera. The quantity of macroinvertebrates collected, especially Oligochaeta, Trichoptera and Diptera, was greater in the fall than in the summer. Benthic organism densities ranged from a low of approximately $4x10^2$ m^{-2} to a high of almost $2x10^4$ m^{-2}.

Species richness was greater in riffle areas, where gravel and cobble substrates predominated; fewer species were collected from pool areas where the substrates were typically sand, mud or litter. Trichoptera, Ephemeroptera, Diptera, Coleoptera, and Plecoptera dominated the riffle sites; whereas, Oligochaeta and Diptera dominated the pool sites. Mollusca were represented by seven taxa, particular- ly the family Ancylidae; the Ancylidae were not, however, found above the proposed diversion point (Figure 6.37-1).

Samples collected nearest Athol were dominated by the Isopod (Asellus) sp., by the net spinning caddisflies (Hydropsyche sp., and Cheumatopsyche sp.) and by the blackfly (Simulium sp.). Downriver locations were dominated by Cheumatopsyche sp., and Hydropsyche sp. below Orange, and midges (Chirono- midae), mayflies (Baetidae) and caddisflies (Hydropsyche sp.) near Millers Falls (Figure 6.37-1).

- Fish

  - Previous Investigations

    Resident Species - Otis (1970) found white suckers and brown bullheads dominating the Millers River fish assemblage, with yellow perch, blacknose dace, golden shiner, common shiner, sunfish and chain pickerel also present.

    An age and growth study (Otis, 1970) of 93 white suckers from the Orange area, found the average lengths for 1, 2, 3, 4, and 5 year fish to be 107, 205, 284, 352 and 377 mm respectively; average lengths for age 1, 2, 3, 4, and 5 year old golden shiners were determined as: 70, 106, 137, 157 and 172 mm respectively.

The environmental quality of the Millers River has increased substantially since Otis' (1970) work, due to a number of successful pollution abatement programs in the Millers drainage (Otis, per. comm.); the river now meets Commonwealth of Massachusetts standards for Class B waters. Due to the cleanup, the numerical importance of rough fish should have diminished. The river now should support more sport fish such as bass, and chain pickerel (McLaughlin, per. comm.; Otis, per. comm.). Lamprey have been observed in the section of river below Orange (Kenard, per comm.) but have not, as yet, actually been observed in the vicinity of Athol.

- Investigations in 1982 - Electroshocking from boats and with backpacks and deploying gill nets produced a total of 173 fish representing 14 species in summer and fall surveys combined (Aquatic Ecology Appendix Table 6.37.2-4). As in the previous survey (Otis, 1970), white suckers predominated (40% by count, 66% by weight). Largemouth bass constituted 10% of the catch by weight, however. Other game fish species found were: brook trout, rainbow trout, and chain pickerel. All species combined, game fish accounted for 12% of the catch by count and 19% by weight.

  Differences in species composition above and below the proposed diversion point (Figure 6.37-1) were quantitatively slight, but qualitatively noteworthy. Brook and rainbow trout were found exclusively above the diversion; whereas, American eel, long nose dace and brown bullhead were found exclusively below the diversion point. Interestingly, no fish were found at the collection site closest to the diversion.

- Threatened and Endangered Species - There were no threatened and endangered species observed during the 1982 investigations nor have any occurrences been reported from the Millers River aquatic study area.

- Selection of Indicator Species - From the inventory and analysis of baseline conditions presented in Section 6.37.1 I, indicator species of macroinvertebrates and fish were selected for the Millers River. The term "indicator species" as applied in this report denotes 1) species representative of aquatic habitats, and 2) species sensitive to the kinds of perturbations that may

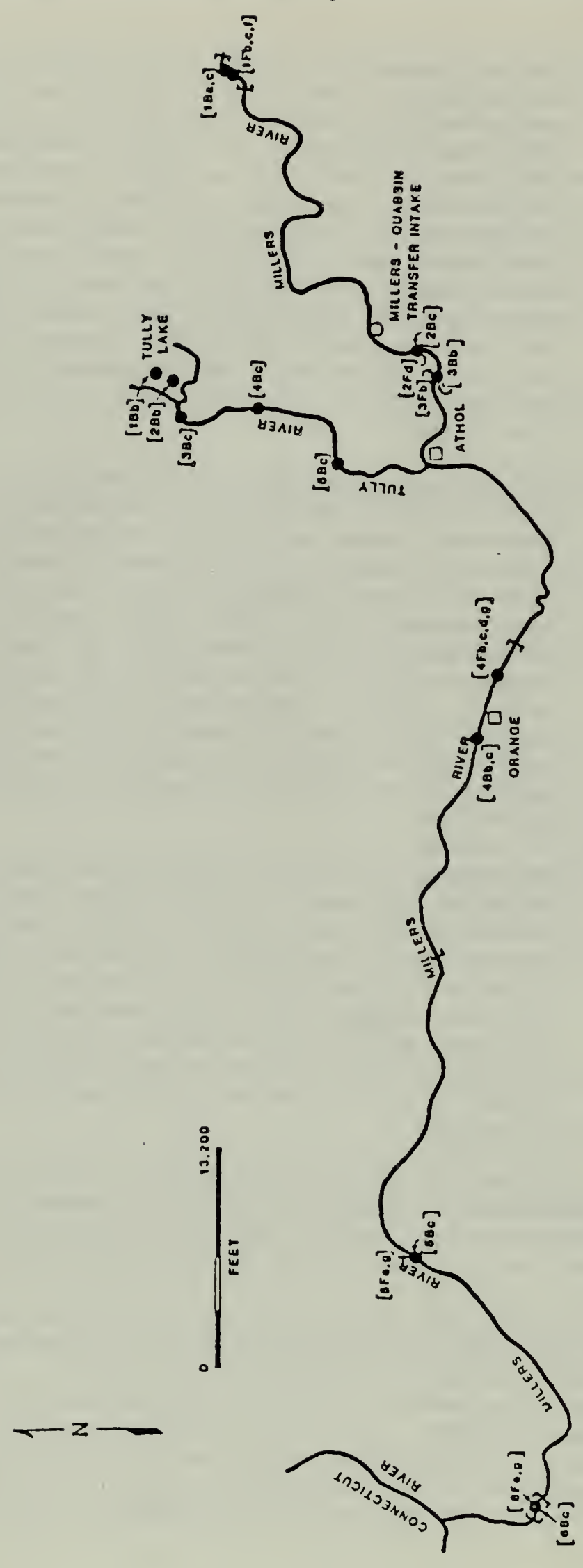


Figure 6.37-1. Benthic Macroinvertebrate and Fish Sampling Stations and Gear Types used during the 1982 NAI Field studies on the Millers and Tully Rivers.

result from development of the Millers River alternative.

The group of species selected is representative of the trophic levels and habitats within the study area, and within potential project impact areas, and will be used to assess impacts of water supply development on these habitats. These species are listed in Table 6.37-1.

The indicator species were selected on the basis of seven criteria; the criteria and the selection process are presented in the report "Task 4: Indicator Species Selection".

II. Future Conditions Without Alternative - Water quality in the Millers River Watershed is affected primarily by land use; therefore, land use changes form the basis of the following projections of habitat conditions and aquatic communities. Land use information was obtained from the area wide Water Quality Management Plan for the Franklin County, Massachusetts 208 area (1977). Projected totals are also likely to be influenced by: 1) zoning law amendments, 2) altered district boundaries, 3) revised community growth plans, and 4) unforeseeable economic conditions. In general, water quality and aquatic habitats are expected to change very slightly over the three time periods projected below.

- 1990 - Two trends are expected to continue in the Millers River: First, fewer violations for municipal waste treatment discharges are expected to occur under the EPA discharge permit regulations. Secondly, low population growth in the area will insubstantiality affect waste loading to the aquatic system. The changes expected in the aquatic communities will be in the direction of increased species diversity and higher productivity.

  Reappearance of migratory fish runs is anticipated although dams will continue to partially restrict upstream and downstream movement until fish passage facilities are constructed at Orange and Athol Dams.

- 2000 - Aquatic community characteristics will be similar to those predicted for 1990, with a continued trend toward improved species diversity and productivity.

- 2020 - Characteristics of the aquatic communities are not expected to differ substantially by 2020 from those projected for the year 2000.

TABLE 6.37-1. INDICATOR SPECIES SELECTED FOR THE MILLERS RIVER AQUATIC ECOLOGY ASSESSMENT.

FISH	SCIENTIFIC NAME	HABITAT TYPE	TROPHIC LEVEL
White Sucker	Catostomus commersoni	Riffle, Pool, Impoundment	Detritivore/ Herbivore Primary Carnivore
Sea Lamprey (Larvae)	Petromyzon marinus	Pool	Detritivore/ Herbivore
Eastern Silvery Minnow	Hybognathus regius	Pool	Detritivore/ Herbivore
Brook Trout	Salvelinus fontinalis	Riffle, Pool	Primary Carnivore
Smallmouth Bass	Micropterus dolomieui	Riffle, Pool	Primary Carnivore Higher Order Carnivore
Atlantic Salmon	Salmo salar	Riffle, Pool	Primary Carnivore Higher Order Carnivore
Shortnose Sturgeon	Acipenser brevirostrum	Riffle, Pool	Primary Carnivore
American Shad	Alosa sapidissima	Riffle, Pool	Primary Carnivore
Largemouth Bass	Micropterus salmoides	Pool, Impoundment	Primary Carnivore Higher Order Carnivore
Redbreast Sunfish	Lepomis auritus	Pool, Impoundment	Primary Carnivore
Northern Pike	Esox lucius	Impoundment	Primary Carnivore Higher Order Carnivore

TABLE 6.37-1. (Continued)

MACRO-INVERTEBRATES	SCIENTIFIC NAME	HABITAT TYPE	TROPHIC LEVEL
Stonefly	*Acroneuria* sp.	Gravel/Cobble	Carnivore
Stonefly	*Taeniopteryx* sp.	Gravel/Cobble, Litter	Detritivore Herbivore
Mayfly	*Ephoron* sp.	Sand, Mud	Detritivore
Caddisfly	*Cheumatopsyche* sp.	Gravel/Cobble	Detritivore Herbivore Carnivore
Caddisfly	*Chimarra* sp.	Gravel/Cobble	Detritivore Herbivore Carnivore
Caddisfly	*Hydroptila* sp.	Gravel/Cobble, Sand, Litter	Herbivore
Caddisfly	*Micrasema* sp.	Gravel/Cobble, Litter	Detritivore Herbivore
Beetle	*Psephenus* sp.	Gravel/Cobble	Herbivore
Flies	*Chaoborus* sp.	Sand, Mud, Litter	Carnivore
Sideswimmer	*Crangonyx pseudogracilis*	Mud, Litter	Detritivore Herbivore Carnivore
Inverted Floater	*Alasmidonta heterodon*	Sand	Detritivore Herbivore Carnivore
Yellow River Mucket	*Lampsilis cariosa*	Sand	Detritivore Herbivore Carnivore

6.37.2 Future Conditions With Alternative

Short term and long term project impacts on aquatic indicator species utilizing potentially affected habitats are summarized by impact category and habitat in the matrix in Table 6.37-2.

I. Short-term Construction Period - Installation of the drop shaft in the riverbed near the north bank and construction of a diversion dam across the river will require temporary rerouting of the river during construction. A cofferdam constructed on the north side to allow work on the drop shaft and half of the diversion dam and to install the fish screens will involve dewatering approximately .6 acres for four to five weeks. Completion of the remainder of the diversion dam after removal of the cofferdam on the outside half of the river will involve dewatering .4 acres for approximately the same time period. The diversion dam will be approximately 8 feet high from the riverbed, and will raise the water level 4-5 feet which will create a small impoundment. Due to the steepness of the banks in this area, the extent of lateral flooding will be minimal.

Benthic indicator species potentially affected represent several different trophic levels. Examples include a detritivore (Ephoron sp.) an Herbivore (Hydroptila), and a carnivore (Chaoborus sp.) (Table 6.37-1). Other taxa potentially affected occupy several different trophic levels. Fish indicator species potentially impacted which represent all major trophic levels include white sucker, eastern silvery minnow, brook trout, shortnose sturgeon and largemouth bass.

The presence of the diversion dam across the river represents a very small loss of benthic habitat. During construction localized disturbance and sedimentation may temporarily disrupt aquatic communities at the diversion site. However, erosion of the riverbed during construction is not a major concern due to the high proportion of cobbles and boulders; erosion from the earthen cofferdam will be controlled using materials such as netting. Moreover, stream communities are accustomed to accommodating naturally occurring sediment influxes during high-water periods, and the proportion of sediment deposited will be small compared to the sediment carried downstream by high flood flows. Dewatering of the riverbed in the areas under construction will result in a temporary loss of habitat for certain forms of benthic macroinvertebrates and fish. However, following the 3 month construction period and resumption of normal flows the substate will restabilize. The diversion dam will not effect downstream flows nor will benthic habitat at the

TABLE 6.37-2. SUMMARY OF IMPACTS OF THE PROPOSED MILLERS RIVER DIVERSION ON MACROINVERTEBRATE AND FISH INDICATOR SPECIES.

	HABITAT TYPE						
IMPACT CATEGORIES:	RIFFLE	POOL	LITTORAL	GRAVEL	SAND	MUD	LITTER
Erosion	X	X	X	X	X		
Water Quality							
Water Quantity	X	X	X				
Water Level	X	X	X				
Habitat Loss/ Change	X	X	X	X	X		
Displacement/ Disruption				X	X		
Entrainment/ Impingement			X				
Vegetation Composition Changes							

construction sites be permanently altered. Upstream flow alteration and sedimentation behind the dam will also not be significant because of the steep gradiant and rapid flow of the river. Based on these considerations, impacts will be well within indicator species tolerance limits, and reestablishment of the conditions requisite to the life cycle requirements of aquatic indicator species populations and communities will be rapid.

II. Long-term - Water quality projections (see Section 6.21.2) for the Millers River predicted that none of the Class B parameters, would be below drinking water standards or adversely affect the maintenance of aquatic life as long as flows were high enough to meet statutory requirements for transfer. These requirements are based on the minimum flow releases necessary to sustain an anadromous fishery. These releases were calculated for each month using the U.S. Fish and Wildlife Service rule for required flow per square mile of watershed; the requirement is higher in April where flushing and anadromous runs are major considerations.

Impacts to macroinvertebrate and fish communities and indicator species, due to changes in water quality, will be insignificant. The diversion dam will include a fishway in order that movement patterns of resident and anadromous fishes will not be adversely affected. Impingement of migratory and resident sport fish species on the intake screens and entrainment of undesirable species to Quabbin have the potential for locally affecting aquatic communities and species populations in the Millers River however.

Entrainment of the lamprey to Quabbin, while not significant from the standpoint of river ecology, could become the most substantive consideration in the Millers River alternative because of the potential impact to the Quabbin sport fishery. Although one-eighth inch mesh screens will control entrainment to an extent, other control measures will be necessary.

Effects of changes in water level during diversion on aquatic communities were also assessed. June was selected as the worst case month because it is the low-flow month having the greatest number of days when maximum transfers could occur (see Section 6.33.2). June is also the breeding period for many macroinvertebrate and fish species, and such activities are normally sensitive to water level changes. Calculations at a section of river having the lowest gradient floodplain demonstrated that, with maximum transfer volumes, the maximum reduction in lateral flooding would be about six feet but that the channel would still be flooded to the top (see Terrestrial

Ecology Appendix Section 6.33.2 for transect location figure and calculation methods for flow/stage relationships). Changes in the amount of river channel substrate available as habitat, and in stream velocities are not expected to be significant. Based on these findings the impacts to aquatic communities due to reduction in water level will be insubstantial.

Habitat losses due to exposure of river channel bottom during diversion were assessed for: (1) loss of substrate and (2) significant current velocity alterations; neither situation is expected, based on available information. The low percentage of available withdrawal periods and proportionally small diversion quantities indicate no long term effects.

- 1990 - Some changes in macroinvertebrate and fish communities due to the proposed transfers may occur as a result of impingement and entrainment at the intake structure. Effects due to water quality and water level changes are not expected to differ substantially from those anticipated without the project.

- 2000 - Changes in macroinvertebrates and fish with the proposed transfer in operation will not differ significantly from the baseline projections to this year without the project except for the possibility of slight changes due to impingement and entrainment.

- 2020 - Projections of the macroinvertebrate and fish baseline to 2020 with the project are not significantly different from those without the project except for the possibility of slight changes due to impingement and entrainment.

6.37.3 Summary of Significant Impacts

Slight changes in community composition and species populations may result due to impingement and entrainment at the intake structure. Introduction to Quabbin Reservoir of undesirable Millers River aquatic fauna may also result. Introductions could include such species as lampreys and carp.

I. Measures of Significance - Macroinvertebrate communities and fish in the Millers River above Montague Dam were identified based on existing information and field surveys, and baseline conditions established. Indicator species representative of the major habitats and trophic levels which will respond to changes resulting from the project were selected (see Indicator Species Report). Project-caused changes in concentrations of water quality constituents affecting aquatic life were evaluated on the

basis of established standards and criteria for maintenance of aquatic life. Species richness and sensitivity of indicator species and species of special concern to changes in water level and parameter concentrations also provided a basis for judging the significance of project impacts.

II. Significant Impacts

- Possible introduction of undesirable species, particularly lamprey, into Quabbin Reservoir via the Millers-Quabbin tunnel.

- Potential changes in community composition and species populations due to impingement and entrainment.

6.37.4 Mitigation/Enhancement Measures

- Update baseline to develop a complete list of undesirable species inhabiting the Millers River in the vicinity of the transfer having potential to be entrained.

- Evaluation of undesirable species life stages and their requirements.

- Set up an impingement/entrainment study at the transfer inlet location to determine species and numbers affected.

- Develop an erosion control plan to control sedimentation before and after construction in the vicinity of the proposed diversion point.

- The following measures have been identified as particularly promising for eradication and control of undesirable species, particularly lamprey:

- Screens. A screen having a mesh size of 1/8" placed at the opening of the diversion tunnel in Northfield Reservoir has been incorporated into the engineering design. This will exclude a high percentage of the larvae and eggs of undesirable species. The screen would be cleaned by means of a backwashing mechanism.

- Sand Filter. A sand filter placed in the diversion tunnel behind the screen would exclude the vast majority of eggs and larvae. However, given the large volumes of water that would be diverted during a given day, the drastic reduction in flow through the sand filter may not be acceptable from a water demand standpoint. More detailed analysis of sand filter thickness and transmissivity rates will be required

before a final assessment of the viability of this technique is possible.

- Electric Current. An electric current pulsed across the opening of the diversion tunnel in front of the screen would be highly effective in eliminating a large proportion of eggs and larvae. More detailed analysis of species specific effectiveness and equipment designs will be necessary in order to completely assess this technique.

- Chemical Control. Lampricides applied to the spawning stream after spawning but prior to emergence of the ammocetes has been effective in controlling the lamprey from the Great Lakes. Diligent application schedules are necessary since survival of even a few larvae to the adult stage would eventually result in a predatory population in Quabbin Reservoir. This technique would be relied upon primarily as a back up with heavy emphasis on one or more of the above techniques for recovering the vast majority of eggs and larvae prior to transfer to Quabbin.

- Thorough analysis of design options, engineering and costs associated with the four methodologies identified above including detailed literature searches and consultation with experts.

Although the above methods have been identified as potential control measures for excluding undesirable species from Quabbin Reservoir, it should be noted that none, either singly or in combination, are known to be completely effective in preventing lamprey entrainment.

Young ammocoetes may be less than 30mm long and 1mm wide which would allow them to pass through all but the finest mesh screen. They are also strong burrowers, and could penetrate a thin, low density filter. The ammocoetes could be killed by continuous application to TFM (3-Triflouromethyl-4-Nitrophenol), a selective lampricide approved by EPA for drinking water.

A solution that has proven effective in the Great Lakes has been to allow colonization, monitor population levels, and treat spawning tributaries with TFM to maintain the population at a level acceptable from the standpoint of managing the sport fishery. Losses of salmonids and other important recreational species by lamprey predation could be mitigated by a stocking program.

6.38 AQUATIC ECOLOGY OF ADDITIONAL PORTION OF MILLERS RIVER AND TULLY RIVER BETWEEN ATHOL AND TULLY LAKE

6.38.1 Baseline Conditions

Biological information is limited to the East Branch Tully River; no existing literature was identified referencing Tully Lake. Moreover, benthic macroinvertebrate information was limited to a qualitative survey by Godfrey (1970). An early fisheries survey was provided by Otis (1970) with more recent data provided by the Army Corps of Engineers (COE, 1980) and Massachusetts Division of Fish and Game (MDFG unpub.).

I. Existing Conditions

- Macroinvertebrates

  - Previous Investigations - Godfrey's (1970) listing of "pollution intolerant" taxa, included: stoneflies (Plecoptera: Acroneuria sp., Leuctra sp.) mayflies (Ephemeroptera. Stenonema sp), dragon flies (Odonata: Aeshna sp.), Megaloptera (Nigronia sp.) and true flies (Diptera: Atherix sp., Simullidae, Chironomidae) (Aquatic Ecology Appendix Table 6.38.1-1). The East Branch Tully River thus appears to be a clean water system, although it drains several bogs, where the water is acidic, creating a hostile environment for certain fish species (Otis per. comm.).

  - Investigations in 1982 - Two distinct physical habitats were sampled by NAI in the spring and fall of 1982: the East Branch Tully River, and Tully Lake (Figure 6.37-1). The flowing (lotic) water environment of the river was characterized by coarse substrates (gravel and cobble). The lake (lentic) benthic habitat consisted of sand, mud, and plant litter.

    Sampling stations on the river yielded up to 58 different macroinvertebrate taxa (Aquatic Ecology Appendix Table 6.38.2-2). The trichoptera alone were represented by 24 taxa, predominantly, Hydropsychidae (Cheumatopsyche sp., Hydropsyche sp., Lepidostoma sp., Chimmara sp. and Rhyacophila sp.). Nine taxa of Ephemeroptera, predominantly Stenonema sp., and Ephemerella sp., were collected. Six pollution intolerant Plecoptera (predominantly Leuctra sp., Phasgonophora sp., and Acroneuria sp.), and ten coleopterans, including members of the families Elimidae and Psephenidae, were also taken. Other

groups well represented in the river samples were Diptera, Megaloptera, Odonata, and Mollusca. In summary, the river in 1982 was richer in species than indicated by previous accounts (Godfrey, 1970).

Individual samples from Tully Lake yielded no more than ten separate taxa each. Tully Lake macroinvertebrate assemblages were dominated by Oligochaeta and Diptera (especially Chironomidae and Chaoboridae). The Ephemeroptera were represented by Caenis sp., and the Trichoptera by Neuroelipsis sp. and Cheumatopsyche sp. The most remarkable find occurred in October 1982 when amphipods of the genus Corophium were collected in substantial numbers. Subsequent sampling in July 1983, the period when this species would most likely be found, failed to collect any of the organisms. This taxa is normally not associated with strictly fresh water and the October finding was probably an anomaly.

- Fish

  - Previous Investigations

Resident Species - Fish collected from an undisclosed segment of the East Branch Tully River (Otis, 1970) included brook trout, white sucker, chain pickerel, yellow perch and brown bullhead.

The East Branch has also been sampled upstream of Tully Lake (COE, 1980). Fish collected there included brown and brook trout, white sucker, brown bullhead, chain pickerel, creek chubsucker and golden shiner. Only six of 22 brook trout collected by electroshocking were over 7.6 cm long. The largest brook trout was 30.5 cm and weighed 304 gms. The two brown trout collected were 27.4 cm and 33.0 cm in length and weighed 236 and 170 gms, respectively.

Lawrence Brook, a feeder stream to Tully Lake, was sampled above and below Doanes Falls (near outlet to Tully Lake) and yielded five brown trout weighing from 125-225 gms (22.9-27.4 cm). Other fish collected included 23 brown bullheads, 18 white suckers, 12 bluegills, ten pumpkinseeds, ten smallmouth bass, five chain pickerel and four darters.

With the possible exception of the brown trout, fish species collected from Lawrence Brook probably also reside in Tully Lake. During the summer of 1982, NAI's survey crew observed local fishermen catching rainbow trout, centrarchids, yellow perch, pickerel, black crappie, and ictalurids in the lake.

The most recent fisheries survey on the East Branch Tully River in the summer of 1981 (MDFG, unpub.) demonstrated the presence of salmonid species. MDFG has maintained a salmonid stocking program on the East and West Branch since 1979. The fish stocked include brook, brown and rainbow trout ranging from 150 mm to over 225 mm in length. This river is heavily fished for trout and will continue to be intensively managed for these species (MDFG unpub. 1981).

Electrofishing near Warwick Road (above Tully Lake) yielded one brook trout (207 mm), one largemouth bass (60 mm), two chain pickerel (150-170 mm), three brown bullheads (80-170 mm) and six white suckers (60-160 mm). Fish collected in the East and West Branch Tully River by electrofishing just above their confluence included one brown trout (186 mm), two chain pickerel (120-270 mm), two white suckers (90-440 mm), nine fallfish (60-80 mm), one chubsucker (70 mm), 15 longnose dace (70-130 mm), 12 tessellated darters (50-70 mm) and 12 American eel (250-480 mm).

Sampling the mainstream of the Tully River, the MDFG (unpublished) collected a largemouth bass (50 mm), a chain pickerel (320 mm), two white suckers (90-210 mm), four fallfish (50-90 mm), 29 longnose dace (60-120 mm), a blacknose dace (60 mm), 14 tessellated darters (50-70 mm) and five American eel (220-400 mm).

This electrofishing survey covered less than half of the stream and recorded a capture efficiency of less than 26%; hence, there were more fish at these stations than the data indicates.

- Threatened and Endangered Species - There were no threatened and endangered species observed during the 1982 investigations nor have any occurrences been reported from the East Branch Tully River aquatic study area.

- Selection of Indicator Species - Given the proximity of the East Branch Tully to the Millers River and the similarity of aquatic habitats, the indicator species selected for the Millers River were also used to assess East Branch Tully River impacts.

II. Future Conditions Without Alternative - As is true for the Millers River, land use changes are expected to occur very slowly in the East Branch Tully River watershed based on the 208 Planning Study (1977). Future characteristics of the aquatic communities over time will reflect natural hydrologic and climatic cycles. Aquatic communities in 1990, 2000 and 2020 are not expected to change substantially, and will continue to be characteristic of clean water habitats.

6.38.2 Future Conditions with Alternative

I. Short-term Construction Period - Installation of an intake and pipeline in Tully Lake, and construction of a vertical drop shaft on the bank at the head of the tunnel system may cause localized sedimentation and disturbance that may temporarily disrupt aquatic communities. If the shaft is constructed in the outlet channel below Tully Lake, a temporary rerouting of the flow will be necessary. As with the Millers River, the impacts are expected to be very localized but of a smaller magnitude. Sediments are likely to be transported downstream, accumulating in pools and temporarily affecting aquatic communities. However, as was stated for the Millers River, stream communities are accustomed to some naturally occurring sediment influxes, and the amount of sediment deposited will be small compared to the amount carried downstream by high flood flows. The amount of sedimentation should be minimized by implementation of a soil erosion control plan; subsequently, recolonization by aquatic communities in the lake and in the river will be rapid.

II. Long Term - As with the Millers River, water quality projections indicated that none of the Class B parameters would be below drinking water standards or adversely affect the maintenance of aquatic life as long as flows were high enough to meet minimum statutory requirement for transfer (Section 6.21.2). At a section of floodplain having the lowest gradient, the maximum reduction in lateral flooding in June with maximum transfer volumes would be about one foot. The channel would remain flooded to the top (see Terrestrial Ecology Appendix Section 6.33.2 for transect location figure) and changes in river channel habitat and in stream velocities will be insubstantial. Consequently, impacts to aquatic communities due to changes in water quality or water level are not expected to be significant. Impingement and entrainment impacts on aquatic communities

and species populations will be possible, however. Future characteristics of the aquatic communities in 1990, 2000, and 2020 will be as predicted for the Millers River; the effects due to water level and water quality changes will not differ significantly from those predicted without the project. Slight changes in aquatic communities may result from impingement and entrainment. Any reduction in flow from the Tully River during diversion will have no effect on water quality or water level in the Millers River because the Tully contributes a very small percentage to the flow of the Millers.

6.38.3 Summary of Significant Impacts

Slight changes in community composition and species populations may result due to impingement and entrainment at the intake.

Tully River aquatic fauna may be introduced into Quabbin Reservoir.

I. Measures of Significance - Measures of significance used in assessing impacts to the Tully River are the same as those used in the Millers River assessment.

II. Significant Impacts

- Possible introduction of undesirable species including lamprey, into Quabbin Reservoir via the Tully-Athol-Millers-Quabbin pipeline.

- Potential slight changes in community composition and species populations due to impingement and entrainment.

6.38.4 Mitigation/Enhancement Measures

The measures recommended for the Millers River are appropriate for Tully River.

6.38.5 Aquatic Ecology Of The Connecticut River

The assessment of the macroinvertebrates and fish for the study area of the Connecticut River is presented in Section 5.31.1. Any change in water quality parameters or flow of the Millers River and/or Tully River will have no effect on water quality or level in the Connecticut River. This is because water quality changes in Millers and Tully Rivers will not be below Class B for drinking water or aquatic life, and the safe yield model for the Millers and Tully Rivers includes the maintenance of a 17,000 CFS minimum flow at Montague as one of the constraints.

6.40 AIR QUALITY

6.40.1 Baseline Conditions

I. Existing Conditions - Despite significant progress by the Commonwealth of Massachusetts in enhancing air quality, violations of the State and National Ambient Air Quality Standards (NAAQS), except for sulfur dioxide and nitrogen dioxide, have continued to occur in Massachusetts. Specifically, the entire state has been designated as non-attainment of the standards for ozone-hydrocarbons while selected communities in the state have been designated as non-attainment for carbon monoxide and the secondary standard for total suspended particulates. The only community for the Millers/Tully Rivers Alternative which is non-attainment for total suspended particulates is the Town of Athol.

Air quality is monitored in the Commonwealth by the Massachusetts Air Sampling Network operated by the Department of Environmental Quality Engineering (DEQE). The results of air sampling measurements are reported in annual summaries published by DEQE [1-5]. Table 6.40-1 presents air sampling data reported for the DEQE stations located in Athol, Northfield, and Greenfield which are the stations closest to the Millers/Tully Rivers Alternative. The measurements at these sites, however, may be used only to a limited extent to extrapolate existing conditions along the project corridor.

Given the regional nature of photochemical oxidant reactions and transport, it is most likely that ozone levels in this corridor are also exceeding standards. The level of total suspended particulates, however, is strongly influenced by local sources. This is evidenced by the Athol monitoring station which is located in the city center where high emission sources are commonly present, while the Northfield station is located in a rural area and does not indicate standards violations. Except for the section of tunnel passing through east and south Athol, the new facilities associated with this alternative are not located near a major emission source making it unlikely that total suspended particulate standards are being exceeded in the project area.

Ambient concentrations of carbon monoxide are also strongly influenced by local sources, particularly heavily travelled streets and roads. Again, the rural character of the project area mitigates against carbon monoxide standards violations.

II. Future Conditions Without Alternative - The exceedance of National Ambient Air Quality Standards (NAAQS) is not unique to Massachusetts but is a condition which is present in

Table 6.40-1 Annual Summary of Air Quality Data

Total Suspended Particulates (uom/m3)

Site	Year	Annual Geom. Mean	Max. 24-Hour Obs.	2nd Max. 24-Hour Obs.	# of Obs. Above 260	# of Obs. Above 150
Athol	1978	42	103	90	0	0
Athol	1979	46	202	127	0	1
Northfield	1979	32	114	101	0	0
Athol	1980	56	158	109	0	1
Northfield	1980	42	95	87	0	0

Ozone (uom/m3)

Site	Year	Max. 1-Hour Obs.	2nd Max. 1-Hour Obs.	3rd Max. 1-Hour Obs.	# of Obs. Above 235
Greenfield	1979	293	293	274	6

many parts of the country. Accordingly, the 1977 Amendments to the Clean Air Act require all states to prepare State Implementation Plans (SIPs) for attainment of standards and submit them for review and approval by the U.S. EPA. These plans must demonstrate attainment of the NAAQS as expeditiously as practicable, but no later than the end of 1982 (or the end of 1987 for areas with serious ozone and/or carbon monoxide problems).

On December 31, 1978 the Governor of Massachusetts and on May 16, 1979, the Acting Commissioner of DEQE submitted revisions to the Massachusetts SIP designed to attain the NAAQS for carbon monoxide and ozone. However, the projections presented in these plans showed that attainment by the end of 1982 was not possible despite the implementation of all reasonably available control measures and that December 31, 1987 is the most expeditious attainment date. Extension of the date for attainment until 1987 has received EPA approval.

- 1990 - By the year 1990, the emissions from virtually every vehicle on the road will be controlled under the present schedule of Federal regulations on motor vehicle emissions. Virtually every vehicle also will require the use of unleaded gasoline. In addition, the Massachusetts motor vehicle exhaust emission inspection program is designed to maintain the performance of the vehicle emission control systems. Therefore, implementation of the revised state plan should result in air quality by 1990 which is consistent with present standards in all parts of the Commonwealth, including the communities affected by the Millers/Tully Rivers Alternative.

  Current legislation mandates a periodic review of present standards in light of new scientific data for the purpose of promulgating revised or new standards. Plans are presently underway to modify the standard for total suspended particulates by promulgating a new standard for inhalable size particulates (particles 10 microns or smaller). This standard may become extant by 1990 and thereby affect a change in air quality levels from those presently considered acceptable.

  Future plans also include establishing new air quality standards for selected toxic substances. Up to 100 such substances may be listed by the year 1990.

- 2000 - In the absence of new legislation mandating stricter standards, compliance with present air quality standards should be maintained in this time period. Pressures from increased population in the communities affected by the Millers/Tully Rivers Alternative may

result in additional atmospheric pollutant burdens. Existing Prevention of Significant Deterioration regulations place some limits on the growth of pollutant emissions.

Air quality standards may be established for toxic substances in addition to the initial list of approximately 100.

- 2020 - Continued increases in the population of the communities along the Millers/Tully Rivers Alternative corridor may result in additional pollutant emissions.

6.40.2 Future Conditions With Alternative

I. Short-term Construction Period - The construction of new facilities required for implementation of this alternative have the potential to affect ambient air quality in several ways, including: (1) exhaust emissions from construction vehicles and equipment, (2) fugitive dust from construction vehicle traffic on unpaved roads, (3) fugitive dust from construction activities, and (4) fugitive dust from wind erosion of exposed land surface.

The principal contaminants emitted by heavy duty construction equipment are carbon monoxide, unburned and partially burned hydrocarbons, oxides of nitrogen and particulate matter. The particulate matter in exhaust emissions consists of both inorganic and organic compounds of high molecular weight. Table 6.40-2 presents emission factors published by the U.S. EPA [6] for various types of heavy duty construction equipment of both diesel powered and gasoline powered likely to be employed. Total emissions will depend on the number of units and the hours of operation for each type equipment. Because this information is not available for the Millers/Tully Rivers Alternative, total emissions from this equipment cannot be estimated at this time.

Fugitive dust will be generated by vehicle movement during construction on unpaved roads and other exposed surfaces involving pulverization and abrasion of the surface materials by the vehicles' wheels followed by entrainment of the dust particles by turbulent air currents. The rate of emission varies with average vehicle speed, vehicle mix, surface texture and surface moisture. The major mass fraction of the particles are relatively large and tend to settle out within a short distance from the source.

Another potential source of fugitive dust arises when land is cleared permitting wind erosion of bare ground. The rate of emission varies with soil texture (specifically the silt content) and soil moisture.

Table 6.40-2 Heavy-Duty Construction Equipment Exhaust Emission Factors

Equipment Class	Carbon Monoxide (grams/hour)	Hydrocarbons (grams/hour)	Nitrogen Oxides (grams/hour)	Particulates (grams/hour)
Heavy-duty equipment Gasoline-powered				
Wheeled tractor	4320	227.5*	195	10.9
Wheeled loader	7060	318.9*	235	13.5
Heavy-duty equipment Diesel-powered				
Tracklaying tractor	175	50.1	665	50.7
Wheeled tractor	973	67.2	451	61.5
Wheeled dozer	335	106	2290	75
Wheeled loader	251	84.7	1090	77.9
Tracklaying loader	72.5	14.5	265	26.4
Off-highway truck	610	198	3460	116

*Includes evaporative and crankcase hydrocarbon emissions

The major new facilities required for implementation of this alternative consist of constructing the weir and bascule gate, and digging shafts, tunnels and outlet structures. Fugitive dust emissions can arise from soil handling operations including land clearing, blasting, excavation, backfill, etc. Estimates of the volume of material moved, land temporarily disturbed, and the associated fugitive dust emissions are presented in Table 6.40-3. Without implementing effective control measures, the largest potential for fugitive dust emissions is associated with the spoil piles. The major mass fraction of these particles are relatively large and tend to settle out within a short distance from the source. The remaining smaller dust particles travel further downwind and generally are considered to be the more hazardous because they tend to be inhalable.

The second largest potential source of fugitive dust is associated with erosion of soil from land cleared for laydown, roads, and work area. The worst case estimate shown in Table 6.40-3 is based on the assumption that half this land area is bare during the full 30-month construction period projected for completion of the project.

Without additional information and modeling analysis, it is not possible to project whether this alternative will result in local violations of NAAQS during this time period.

II. Long-term - The principal long-term impact from the Millers/Tully Rivers Alternative arises from the continued energy consumption required to operate the system. Projected annual power consumption for this alternative is 64,103 Kw-hr. This impact is an indirect one because the on-site electric power demand is generated at an off-site facility.

Electricity is generated by fossil-fuel power plants, nuclear power plants and hydroelectric power plants. Because the mix of electric generating plants supplying electrical power to operate the facilities associated with this alternative cannot be predicted, worst case emission conditions have been evaluated. Table 6.40-4 presents calculated annual emissions on the assumption that the power is generated by coal-fired or oil-fired units burning fuel containing the maximum sulfur content presently allowable under Massachusetts regulations.

For the same reason that the level of emissions cannot be uniquely determined, the location of these emission sources cannot be predicted. Consequently, the impact on local air quality cannot be estimated for this alternative.

- 1990 - The indirect source of gaseous and particulate emissions described above can be expected to continue to be present in this time period. The specific mix of

Table 6.40-3 Estimates of Fugitive Dust Emissions from Construction*

Activity	Volume Earth Moved (cu yds)	Fugitive Dust (tons)
Millers River Alternative		
Quabbin Spoil Pile:		
Direct Tunnel Outlet	162,963	326
Deep Channel Outlet	348,148	696
All Other Spoil Piles:	153,556	307
Land Temporarily Disturbed:		
Exposed area 5.0 acres		90
Millers/Tully River Alternative		
Quabbin Spoil Pile:		
Direct Tunnel Outlet	188,889	378
Deep Channel Outlet	370,370	741
All Other Spoil Piles:	253,704	507
Land Temporarily Disturbed:		
Exposed area 7.0 acres		126

*Before the application of control measures.

Table 6.40-4 Estimated Annual Power Plant Emissions From Electric Energy Demand

Coal-fired	Coal[1] (tons)	Sulfur Oxides (tons)	Carbon Monoxide (tons)	Hydro-carbons (tons)	Nitrogen Oxides (tons)	Particu-lates[2] (tons)
	32	1	<0.1	<0.1	0.3	<0.1
Oil-fired	**Residual Oil[3] (bbl)**					
	116	0.9	<0.1	<0.1	0.3	<0.1

[1]Assumes 1 lb coal input per Kw-hr output

[2]Maximum emission rate of 3.9 lbs per ton of coal fired.

[3]Assumes 0.6 lb residual oil input per Kw-hr output.

power plant fuels used to generate the electrical energy demand for this alternative will dictate the additional pollutant burden.

- 2000 - Because of a continuing demand for electrical power for this alternative, the indirect source of gaseous and particulate emissions described above can be expected to continue to be present.

- 2020 - Although the demand for electrical power for this alternative will continue, the significant changes in fuel use patterns predicted for this era, particularly a reduction in the consumption of fossil fuels, would lower the potential for power plant pollutant emissions.

6.40.3 Significant Impacts

I. Measures of Significance - National Ambient Air Quality Standards for six pollutants were promulgated by the EPA on April 13, 1971. These pollutants are sulfur oxides, nitrogen oxides, carbon monoxide, photochemical oxidants, hydrocarbons, and total suspended particulates. A national ambient air quality standard for lead was promulgated on October 4, 1978, and the photochemical oxidant standard revised to an ozone standard on February 8, 1979. On January 5, 1983 the EPA revoked the standards for hydrocarbons. These national standards are minimums that all states are required to adopt. The primary standards, listed in Table 6.40-5, are intended to protect the public health, while the secondary standards are intended to protect the public welfare from any known or anticipated adverse effects. The table shows that the primary and secondary standards for those pollutants which are largely transportation related prescribe the same levels. Emissions from transportation sources are not expected to be a major factor in this alternative except from heavy duty construction equipment.

II. Significant Impacts - Increased emission of air pollutants over those presently occurring without the alternative can be expected as a consequence of implementing the Millers/Tully Rivers Alternative. The principal short-term increase can be expected in the form of fugitive dust arising during the construction of the additional facilities required. Local violations of particulate standards could occur due to fugitive dust associated with construction activities unless control measures, such as those described below, are enforced. Additional emissions of carbon monoxide, nitrogen oxides, hydrocarbons and particulates also can be expected from the exhausts of the construction equipment used. The likelihood of violations of carbon monoxide or nitrogen oxide standards cannot be estimated with the data available at this time.

Table 6.40-5 Massachusetts and National Ambient Air Quality Standards

Pollutant	Averaging Interval[1]	Primary Standard (uom/m3)	Secondary Standard (uom/m3)
Sulfur Dioxide	Annual	80	--
	24-hr	365	--
	3-hr	--	1,300
Total Suspended Particulates	Annual	75[2]	60[2,3]
	24-hr	260	150
Nitrogen Dioxide	Annual	100	100
	1-hr[4]	320	--
Carbon Monoxide	8-hr	10[5]	10[5]
	1-hr	40[5]	40[5]
Ozone	1-hr[6]	235	235
Lead	3-mo[7]	1.5	1.5

[1]Standards other than those based on annual arithmetic means or annual geometric means are not to be exceeded more than once per year.

[2]Annual geometric mean.

[3]To be used as a guide for assessing implementation plans to achieve the 24-hour standard.

[4]DEQE guideline applicable only to major nitrogen oxide sources.

[5]Values shown are in units of mg/m3.

[6]Standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above standard is equal to or less than one.

[7]Maximum arithmetic mean averaged over a calendar year.

Any effects from increased hydrocarbon emissions from construction equipment on ambient ozone levels would probably not be evident within the local communities, but would be manifest along downwind trajectories. Identification of the location and extent of these impacts requires additional highly complex modeling analysis.

Long term impacts on air quality can be expected to arise from the combustion products of fossil fuels burned at offsite generating stations to supply the electrical power demands of the new diversion facilities. The significance of this impact cannot be evaluated due to the uncertainty of the location and mix of power plant fuel consumption.

6.40.4 Mitigating/Enhancement Measures

The potential increases in air pollutant emissions can be mitigated by the application of a variety of control techniques. Control of fugitive dust is specifically required under Massachusetts regulation 310 CMR 7.09. Common non-chemical control techniques for unpaved roads include watering and traffic control. Watering can reduce emissions by 40-50 percent, but may require frequent retreatment during certain seasons to be effective. Spoil piles in particular require treatment to minimize wind erosion. All trucks should be hosed and washed clean of mud and dirt clinging to the wheels and exterior body surfaces to prevent mud and dust from being carried onto paved roads.

Reduction in the exhaust emissions from trucks and other heavy equipment can be achieved by restricting idling when these units are not in use.

Reductions in long-term emissions could be achieved through the implementation of energy conservation measures.

BIBLIOGRAPHY

1. Commonwealth of Massachusetts, Department of Environmental Quality Engineering. 1978. Massachusetts Air Quality Data Summaries. Boston, MA.

2. Commonwealth of Massachusetts, Department of Environmental Quality Engineering. 1979. Air Quality Data Report. Boston, MA.

3. Commonwealth of Massachusetts, Department of Environmental Quality Engineering. 1980. Air Quality Data Report. Boston, MA.

4. Commonwealth of Massachusetts. Department of Environmental Quality Engineering. 1981. Air Quality Data Report. Boston, MA.

5. Commonwealth of Massachusetts. Department of Environmental Quality Engineering. 1982. Air Quality Data Report. Boston, MA.

6. U.S. Environmental Protection Agency. 1977. Compilation of Air Pollutant Emission Factors, Third Ed., Parts A and B (including Supplements 1 - 7) Pub. AP-42. Research Triangle Park, NC.

6.41 NOISE

In operation, this alternative water source is not expected to increase existing ambient noise levels. Construction noise can be expected to be high in the vicinity of shafts and intake and outlet structures. The construction period is expected to be about two and a half years. Groundborne sound from blasting and tunnel boring can also be expected, although much of the proposed route is in presently unpopulated areas and the tunnel is 300 ft. or more below grade for much of its length.

6.41.1 Baseline Conditions

I. Existing Conditions - According to topographic maps dated 1970 through 1977, most of the approximately ten mile long tunnel route encounters very few dwellings. About two miles of the proposed tunnel route lie under the town of Athol, a town with a relatively low population density. The tunnel route intersects existing sources of noise including federal Route 202 in New Salem, state Route 2 near Athol and the Boston and Maine railroad tracks twice, in Athol and again near the Millers River shaft. Except at existing noise sources and in Athol, daytime and nighttime noise levels are likely to be 25 to 30 dB(A).(1)

II. Future Conditions Without Alternative - Increased vehicular traffic and, possibly, the railroad will remain the predominant sources of noise in this area. A seasonal source of noise affecting the general area and likely to increase in occurrence is the general aviation traffic associated with the Orange Municipal Airport, a popular facility for skydiving, about 3 miles southwest of Athol.

- 1990 Existing ambient noise conditions will probably remain unchanged.

- 2000 Existing noise conditions will remain in effect unless population density changes occur or major noise producing facilities are constructed. Enforcement of noise emissions regulations for trucks, aircraft, trains and other transportation methods could reduce ambient noise levels, despite increased traffic.

- 2020 Noise conditions will probably be similar to those reached in 2000 unless further population density changes occur or major noise generating facilities are added.

6.41.2 Future Conditions With Alternative

I. Short-Term Construction Period - The construction period of the tunnel is expected to be about two years. The most obvious noise sources will be trucks hauling the excavated material from shafts and tunnel to nearby spoil piles. There will also be groundborne noise generated by blasting and boring. The shafts and some fraction of the tunnel is expected to require blasting, the rest boring. Depending on the geological strata, distance, and the water table, these groundborne noises may be audible (boring) and feelable (blasting) inside nearby buildings. Inlet structures at Tully Lake and outlet structures at Quabbin will be constructed within a 12-month period and involve conventional construction equipment. Means of controlling noise from construction equipment are well known and means of warning residents of unusual sporadic noises or vibrations due to blasting are generally accepted practice. In situations where a potentially severe impact is expected, the noisy activity may need to be scheduled to only occur during weekday daytime periods.

II. Long-Term - During normal operations, this alternative is not expected to generate any objectionable noise. Water rushing out of the tunnel into the Quabbin Reservoir may be quite loud at close proximity but should be inaudible outside the MDC-owned watershed area, typically one mile or more from the two proposed outlets.

- 1990 No anticipated audible noise at presently developed residential land use areas.
- 2000 No objectionable noise.
- 2020 No objectionable noise.

6.41.3 Significant Impacts

I. Measures of Significance - Noise emissions from source facilities should not exceed nighttime ambient noise at affected receivers by more than 10 dB.(2) The reference ambient noise conditions are the local ambient noise levels at the closest noise-sensitive land use boundary measured prior to the facility preliminary design phase.

II. Significant Impacts - The noise sources associated with water transfer are quiet and well removed from residential land use. Therefore, the facilities associated with the Millers/Tully River Alternative represent no potentially significant long-term noise impact.

6.41.4 Mitigation/Enhancement Measures

If necessary, construction noise can be controlled by contract specifications requiring properly muffled engines and limiting hours of operation to normal weekday daytime periods. Sporadic noise and vibration from blasting could produce annoyance, and a means of alerting nearby residents to such activities should be provided. Public information and liaison should be provided during the construction period.

Preconstruction surveys of houses near blasting areas should be conducted to establish existing cracks and other defects which could be increased by blasting activities.

BIBLIOGRAPHY

1. U.S. Environmental Protection Agency, Community Noise, Rept. NTIC 300.3, 31 December 1971, p. 22.

2. Department of Environmental Quality Engineering, Guidelines for Application of 310 CMR 7.10.U, Noise.

6.50 LAND USE

6.50.1 Baseline Conditions

I. Existing Conditions. Facilities for these two alternatives will be located in the towns of Athol, Orange and New Salem. Existing land use in the two towns (based on the MacConnell land classification information - 1971) is summarized in the following table. Undeveloped land is defined as the total acres of land in the forest and agriculture categories. The existing land use conditions in the potential service area communities are described in the technical appendix report: Task 4: No Action Alternative Assessment Report; this information is used to assess indirect impacts.

Table 6.50-1: Existing Land Use

TOWN	FOREST	WETLND	AGRI.	URBAN	OPEN & PUBLIC	MINING & WASTE	OUTDR RECRTN	TOTAL* ACRES
Athol	74%	5%	9%	10%	0%	0%	1%	
	15752	1136	1917	2139	103	111	203	21361
New Salem	71%	25%	3%	0%	0%	0%	0%	
	27029	9585	1205	170	8	7	0	38004
Orange	77%	4%	10%	8%	1%	1%	0%	
	17437	791	2319	1736	135	131	31	22580

*Percents rounded, may not equal 100%

- Recreation. The existing recreational facilities and activities are discussed on a regional basis in the land use section of the report: Task 4. No Action Alternative Assessment Report. The baseline recreational information is based on the "Statewide Comprehensive Outdoor Recreation Plan (SCORP)" published in 1976 by the Department of Environmental Management; this report established seven planning regions and surveyed recreational facilities across the state. The communities affected by the Millers and Millers/Tully River options are included in the data for Regions II and III of the SCORP Report.

  Facilities for this alternative will be sited in only one public recreational area. Quabbin Reservoir, managed by the MDC, encompasses approximately 24,960 acres and provides opportunities for shore and boat

fishing, picnicking and hiking. However, recreational privileges are offered only when consistent with Quabbin's main purpose of supplying water for the Metropolitan Water District.

Currently, there is a considerable amount of canoeing, kayaking, and rafting water-based recreation on the Millers River, and according to the Department of Environmental Management's Scenic Rivers Program, part of the river is a Class IV water area. In the spring, the Athol River Rat Race with over 100 entrants takes place from Athol to Orange and commercial raft trips are operated from Millers Falls. White water areas are located from Erving to Millers Falls and at Royalston, although the area at Royalston is not used as heavily as the former area. There is also a flat boating area between Athol and Orange which is where the Athol River Rat Race takes place.

II. Future Conditions Without Alternative. Because of the very slow growth rates being experienced in Athol, New Salem and Orange, it is not expected that the land use patterns in the three towns in 1990 will differ significantly from those patterns described above in Existing Conditions. The future land use distribution in the potential service area communities is discussed in the land use section of the Task 4: No Action Alternative Assessment Report.

6.50.2 Future Conditions With Alternative

I. Short-term Construction Period. There would be construction period land use impacts from those facilities that require the temporary use of land not acquired in fee simple. The Millers River option would require temporary easements over a total of four acres of land and the Millers/Tully River option would require temporary easements on five acres of land for construction access roads and contractor work areas. It is assumed that the cost of the easement when privately-owned land is involved would reflect the degree of disruption/inconvenience to the landowner.

II. Long Term

- Direct Land Use Issues. Direct land use issues would result from the land required to construct the necessary facilities and from permanent easements required for access to facilities. The cost of permanent easements on land totalling 0.5 acres and 1.0 acres for the Millers and Millers/Tully River Alternatives, respectively, would reflect the degree of disruption/inconvenience to the landowner; these

easements, necessary for permanent access to facilities, would not result in substantial land use impacts.

The Millers River and Millers River/Tully options would require the acquisition of 19 acres and 32 acres, respectively, of privately-owned land. The 19 acres necessary for the Millers River Alternative are located in Athol. The land is currently wooded, undeveloped land; the amount to be acquired represents 0.1 percent of the undeveloped land in Athol. The Millers River/Tully Alternative will require the acquistion of 29.5 acres of wooded, undeveloped land in Athol and 2.5 acres of wooded, undeveloped land in Orange; the amount of land to be acquired represents 0.2 percent and 0.01 percent of the total undeveloped land in Athol and Orange, respectively. These land acquisitions would not result in signifcant changes in the land use patterns in either town. The land will be used for intake structures, shafts, spoil piles and access roads. In both alternatives, the Athol spoil pile will require 12 acres of land.

A management plan has been designed for the Millers River, as a first step in the process of designating it as a Scenic River in the Massachusetts Department of Environmental Management Scenic Rivers Program. The plan, prepared in 1983, includes a series of recommended land use regulations which have not yet been drafted and adopted by the individual towns. The Millers River spoil pile, shaft and intake structure, requiring approximately 6.5 acres of riverfront land, should not have a significant impact on riverfront land use due to the undeveloped character of that stretch of the river.

- Indirect Land Use Issues. Indirect land use impacts would result from changes in the ability of the potential service area communities to accommodate additional development. The potential future development and the availability of suitable land to accommodate this growth is discussed in Task 4. No Action Alternative Assessment Report. The safe yield increase provided by this alternative, between 33 and 38 MGD, is less than the projected total water need of the MDC in the year 2020; the alternative would not adequately supply the total needs of the system. In certain limited situations, users would not be provided water to meet their projected needs as a result of the shortfall. Because the lack of adequate water can constrain growth at the community level, changes could occur in some community land use patterns in communities which are not able to provide

an adequate water supply. A more detailed analysis of these minor land use changes is beyond the scope of this study.

- Recreational Issues. The Quabbin Outlet Structure, shaft and spoil pile for both the Millers and Millers/Tully River Alternatives will all require the use of land within Quabbin Reservoir. The amount of land required is dependent upon whether the direct outlet or deep channel outlet option is used. Construction of the direct outlet would require the use of a total of 23.5 acres of land; the deep channel outlet would require 52.5 acres of land. In both cases, the majority of the land would be used for the spoil pile (23 and 46 acres, respectively). The total amount of land required for the direct outlet represents 0.2 percent of the land in Quabbin Reservoir; the land needed for the deep channel outlet represents 0.09 percent of the land in Quabbin Reservoir. The use of this small amount of land would not have a significant impact on recreation in the Quabbin Reservoir area.

  The spoil piles and shaft will be located in the northern portion of Quabbin Reservoir, just to the east of a shore fishing area and to the southeast of a boat launching area. The piles are large mounds of excavated soil and rock, a few feet higher than the surrounding area; they would be replanted with grass or low shrubs. Following construction, the visible portion of the shaft would consist of a concrete cap, approximately 20 feet in diameter, slightly above grade. A fence would be used to enclose an area approximately 40 feet square, immediately surrounding the shaft. The spoil piles and shaft should have no impact on activities in the area. The outlet structure (either type) would be located near a shore fishing area in the northern part of the reservoir. The direct tunnel outlet would consist of a concrete-lined, open channel (approximately 40 feet wide) with a fence around it. The deep channel outlet would not be fenced, but a fence would be erected around the concrete structure at the head of the channel. The outlet structures would have some visual impact on the area, but would not preclude recreational activities in the surrounding area.

  The recreational activities on the Millers River that are white-water kayaking would be affected by this alternative in the area around Royalston. The take out point for the diversion lays within this stretch of white-water and the placement of the weir would interrupt the access to some white-water areas in the

lower reaches of this run. It does not appear that impacts will take place in the run from Erving to Millers Falls since the minimum flow required for the diversion to take place are well above the gage readings considered of medium quality of white-water activity.

- Traffic Issues. Possible traffic impacts would generally result from truck traffic to and from the treatment plant for chemical deliveries; however, since there is no treatment plant for this alternative, there would be no chemical deliveries, and there would not be any resultant impacts. One visit per day would occur for maintenance and inspection which would result in almost no traffic change, with one vehicle at the intake and outlet structures.

- Competing Users. In the Planning Area Report, it was determined that for the Millers River/Tully Alternative, the communities along the river including the Towns from Athol to Montague would be considered as possible competing users. This includes the communities of Athol, Orange, Wendall, Erving, and Montague. These communities are included as potential competing water users because they are potentially affected by a five percent reduction of streamflow in the river as a result of this alternative. Based on the water supply data reported to the Division of Water Supply in the Department of Environmental Management (1982) and population projection from the regional planning agencies, the Town of Athol is projected to experience a water supply deficit during the planning period. However, if this alternative is implemented, Athol could be provided water by the MDC which would eliminate any impact as a competing user.

6.50.3 Significant Impacts

I. Measures of Significance. The method for determining the significance of the land use and recreational impacts is discussed in the Selection and Assessment Criteria Appendix.

II. Significant Impacts. The direct land use impacts possible under the Millers and Millers/Tully Rivers Alternatives are not significant due to the very small change (less than 0.3 percent) involved in the community land use pattern. To the degree that indirect land use impacts have been identified, they would not be significant. Recreational impacts resulting from these alternatives also would not be significant in Quabbin and the Millers River.

6.50.4 Mitigation/Enhancement Measures

Landscaping around the outlet structure and shaft would help to minimize the visual impacts on Quabbin Reservoir.

The construction of a take out point and parking in the Royalston run would allow reduction in impacts on white-water activity in that area.

6.60 SOCIO-ECONOMIC IMPACTS

The Millers River alternative provides an additional 33 MGD to the safe yield of the MDC water supply system at a total capital cost of $83.3 million, and the Millers/Tully River alternative provides an additional 38 MGD to the safe yield at a cost of $112.5 million (in 1982 dollars). On the basis of this examination, the socio-economic impacts associated with this alternative are expected to be minor except at the local level during construction. Three categories of direct socio-economic impacts were examined to enable consistent comparison with other alternatives: direct employment, direct costs, and indirect and induced employment.

6.60.1 Baseline Conditions

I. Existing Conditions - The socio-economic baseline was profiled for the MDC potential service area including 44 current user communities and 13 potential future user communities in the Task 4. No Action Assessment Report.

II. Future Conditions Without Alternative - Key socio-economic characteristics were profiled for the planning area communities. Forecasts were prepared for milestone years during the planning period:

	1980	1990	2000	2020
Current Users Population	2,455,417	2,264,430	2,443,193	2,605,579
Potential Future Users Population	244,332	257,897	312,339	340,949
Current Users Households	783,605	835,351	945,106	1,014,534
Potential Future Users Households	68,963	83,137	105,363	116,514
Current Users Employment	1,277,215	1,443,276	1,547,125	1,836,037
Potential Future Users Employment	114,551	137,010	152,008	179,621

In addition, the MDC wholesale water rates and present retail water rates in individual planning area communities were inventoried. The MDC wholesale water rate in 1983 was $240 per million gallons. The MDC wholesale rate was raised slightly in early 1984 to $245 per million gallons. Community water rates were obtained directly from the communities during the Summer and Fall of 1982 and reflect the levels and structures in place at that time. In the

period since the passage of Proposition 2½, many Massachusetts communities have increased their water rates by up to 100 percent to reflect the "true cost" of delivering that service. When community rate data were collected, 10 MDC communities had increased water rates to fully recover operating costs. Under the baseline forecasts, it is assumed that by 1990 all communities will be charging rates at the full-cost recovery level, as permitted under Proposition 2½; these levels are equivalent to about $1.00 per hundred cubic feet of $1,337 per million gallons. (For a more detailed discussion of rates and water pricing, see Task 4: No Action Assessment Report and Section 3.23 of the Demand Management Report.)

6.60.2 Future Conditions With Alternative

The following types of employment impacts were considered for both the short and long term: direct employment impacts include that employment which occurs as a direct result of the construction/installation, operation and maintenance of a new alternative, in this case, construction and operation. Indirect and induced employment impacts include that employment associated with purchases of materials or services for the alternative and other employment occurring as a result of stimulated economic activity.

I. Short-term Construction Period - This alternative involves construction of a tunnel facility and pipeline system to divert water using gravity flow from the Millers and Tully Rivers. The employment impacts associated with both were examined. As summarized in Table 6.60-1, the short term employment impacts are moderately significant during the course of construction, under both options. Direct employment impacts associated with design and construction of the tunnels, pipelines and other components of the facilities are equivalent to 746 person years through the construction period in the Millers River alternative and 2,045 in the Millers/Tully Rivers alternative. Depending on the extent to which construction materials and services are purchased from within the region, indirect and induced employment associated with construction may be as high at 1,410 person years in the Millers alternative and 2,045 person years in the Millers/Tully alternative. This total impact, in either option, is equivalent to about slightly more than 0.1 percent of planning area employment in 1990.

II. Long term - Since a low staffing level is required to operate the facilities under either the Millers or Millers/Tully alternative, long-term direct employment impacts are estimated to be equivalent to only 5 to 8 person years, annually. Because the principal operating expense is

energy, the indirect and induced employment impacts are also expected to be minor--equivalent to less than 100 person years, annually.

In addition, the following cost impacts were considered: Direct cost impacts include the changed costs of water supply associated with implementation of an alternative to the MDC, to the local water department and to individual rate payers.

This Millers River alternative provides the MDC with an additional 33 MGD of safe yield at a cost of $142.15 per MG in terms of net present value. The Millers/Tully River alternative requires a larger tunnel shaft and additional piping to connect the Tully River to the Millers River Quabbin system. As a result, the Millers/Tully River alternative is more costly; it provides the MDC an additional 38 MGD of safe yield at a cost of $170.22 per MG in terms of net present value. The net present value of each alternative has been determined as a basis for comparing alternatives. As shown in Table 6.60-1, if the marginal annual cost of amortized capital and operations and maintenance per million gallons of yield is used as a basis of comparison, the marginal cost of the Millers Alternative would average $401/MG in the years 1990 through 1994 (or 164 percent of the present wholesale rate) and $93/MG in years 2010 through 2014 (or 38 percent of the present wholesale rate). The marginal cost of Millers/Tully Alternative would average $475/MG (or 198 percent of the present wholesale rate) and $112/MG (or 45 percent of the present wholesale rate), respectively, in the early and later planning periods.

If these impacts are spread over all MDC users, rates associated with the Millers Alternative would be increased by $39/MG (or 16 percent of present wholesale rates) and $9/MG (or 4 percent of present wholesale rates), respectively, in early and later periods. This would translate to at least 3 percent and 1 percent retail rate impact, respectively, if wholesale rate impacts are passed on directly to consumers. With the Millers/Tully Alternative, if wholesale rates are distributed equally across MDC users, wholesale rates would be increased by $53/MG (or 22 percent of present wholesale rates) and $13/MG (or 5 percent of present wholesale rates), respectively, in early and later years. This in turn translates to a 4 percent and 1 percent retail impact respectively.

The total cost estimates also assume that the increased MDC capacity will be fully utilized, that is, that consumption will increase from 300 to 33 MGD and 338 MGD, respectively, for the Millers and Millers/Tully Alternatives.

TABLE 6.60-1

SUMMARY OF IMPACTS ASSOCIATED WITH
MILLERS/TULLY RIVER ALTERNATIVE

	Millers River	Millers/Tully Rivers
Employment Impacts		
- Construction (person years during the period of construction)		
-- Direct	705	1,010
-- Indirect/Induced	1,320	1,900
- Long Term (average annual person years)		
-- Direct	5	7
-- Indirect	<100	<100
Cost Impacts		
-- Additional Safe Yield	33	38
-- Net Present Value Per Million Gallons	$ 142.15	$ 170.22
-- Wholesale Rate Impacts:		
Early Years	$39/MG (16%)	$53/MG (22%)
Later Years	$9/MG (4%)	$13/MG (5%)
-- Retil Rate Impacts:		
Early Years	3%	4%
Later Years	1%	1%

At the level of individual consumer, the anticipated retail water rate increased will have a minimal effect on demand (less than 0.15 percent) due to the relative inelasticity of demand for water in response to changes in price.

6.60.3 Significant Impacts

I. Measures of Significance - Significant employment impacts at the community level are those involving direct employment greater than 100, and at the regional level, direct employment greater than 500. Significant cost impacts are anticipated to be equivalent to water rate increases exceeding double the rate of inflation over a five year period.

II. Significant Impacts - The only significant impacts associated with this alternative occur during the construction period, when direct employment at both the local and regional levels exceed the measures noted above. The direct cost impacts are insignificant, although the Millers River alternative results in a slightly more favorable direct cost impact on water rates than the Millers/Tully River alternative. The cost impacts in either option are considered to be insignificant.

6.70 SIGNIFICANT CULTURAL RESOURCES

6.70.1 Baseline Conditions

I. Existing Conditions The project area for the Millers and Millers/Tully Alternatives is located in rugged upland terrain between the Millers and Swift River Valleys. Documented prehistoric occupation and utilization of this area dates back to as early as the Paleo Indian Period (ca. 12,000 - 9,000 years ago), and spans the entire range of cultural periods currently recognized in prehistoric New England. Recent analysis of prehistoric artifact collections demonstrates the presence of over 40 prehistoric sites in the former Swift River Valley, now part of the Quabbin Reservoir and watershed (Massachusetts Historical Commissions Files). The majority of prehistoric sites in the area are likely to be found on river terraces, and in low-lying terrain near lakes, ponds, streams, and wetlands. In general, fewer prehistoric sites are likely to be found in the rugged uplands, which were utilized primarily as resource exploitation zones (cf. Dincauze et al. 1976: 10-26).

Historical settlement in the project area, which includes portions of the present towns of Orange, Athol, and New Salem, consisted predominantly of small agricultural communities located along the principal transportation corridors. Small industrial centers developed along the major waterways, especially the Millers River. Most of the upland areas in these towns remained undeveloped, although they were utilized to a limited extent throughout the Historical Period for agriculture, livestock-raising, and lumbering (MHC 1982a, b).

At the present time, no prehistoric or historical sites are recorded within the impact area of the proposed facilities for the Millers and Millers/Tully River Alternatives.

II. Future Conditions Without Alternative Without a full evaluation of the location and condition of all potentially significant cultural resources at the proposed facility sites for the Millers and Millers/Tully River Alternatives, an adequate assessment of future impacts without the alternative is not possible. Apart from the adverse effects of development or other land modifications, significant impacts upon existing cultural resources are not likely to occur.

6.70.2 Future Conditions With Alternative

I. Short-term Construction Period A number of facilities proposed for the Millers and Millers/Tully River Alternatives will have a potential adverse impact on cultural resources. These include the construction shafts, their spoil piles; the Quabbin Outlet (Direct Tunnel, Deep Channel options); and related access roads, laydown areas, and work areas. The proposed tunnel from the Millers River or the Millers/Tully River will not disturb cultural resources because surface disruption during the tunnel construction will be limited to the shaft sites.

The construction of facilities for the Millers and Millers/Tully River Alternatives will result in two types of impact on cultural resources that may exist at the facility sites: 1) Primary archaeological impacts involve extensive or total disruption of the ground surface, resulting in the destruction of cultural resources. 2) Secondary archaeological impacts involve intermittent or sporadic disruption or compaction of the ground surface, resulting in limited disturbance to, but not complete destruction of, existing cultural resources. In general, construction at the various facility sites will include both primary and secondary impacts in differing amounts.

The principal construction-related impacts of the Millers River Alternative are listed below by facility, total acreage of disturbance, and type of anticipated archaeological impact.

- Shaft Sites (8.25 acres)--Primary archaeological impacts will occur from the construction of the tunnel shafts, with a small amount of secondary archaeological impacts from access road construction and work areas.

- Spoil Areas (51.5/74.5 acres)--Secondary archaeological impacts will result from clearing, movement of heavy machinery, soil compaction, and access road construction. If the Direct Tunnel Outlet is constructed, total disturbed area for the Millers River Alternative amounts to 39.5 acres; if the Deep Channel Outlet is chosen, this figure increases to 62.5 acres.

- Quabbin Outlet Structure (2.5/9.0 acres)--Primary archaeological impacts will occur from construction of either the Direct Tunnel Outlet (2.5 acres) or the Deep Channel Outlet (9.0 acres). Some secondary archaeological impacts may result from road construction and work areas.

II. Long-term Impacts In general, construction impacts on cultural resources will produce irreversible disturbance or destruction to archaeological sites. Long-term impacts are not likely to occur once the proposed facilities are constructed. One potential long-term positive impact, however, must be considered. This involves the potential impact of the implementation of the Millers and Millers/Tully River Alternatives upon archaeological sites within the Quabbin Reservoir. The addition of a new source of water into the reservoir may have a number of effects on the sites that currently exist, both in the reservoir, and along its margins. Although the maximum pool elevation of the Quabbin Reservoir will not exceed 530 feet (U.S.G.S. Datum), the average water level in the reservoir may be higher for longer periods of time if the Millers or Millers/Tully River Alternative is implemented. This may serve to protect archaeological sites that are now currently flooded for most of the time but are occasionally exposed to erosion and vandalism during drought conditions. On the other hand, archaeological sites that are located on the margins of the reservoir may suffer accelerated attrition from the effects of erosion from the increase of water flowing into the reservoir. Further study is required to evaluate in detail the potential effects of the introduction of water from the Millers and Tully Rivers on cultural resources surrounding the Quabbin Reservoir shoreline.

6.70.3 Significant Impacts

I. Measures of Significance Archaeological sites are considered significant if they are listed in, or eligible for inclusion in, the National Register of Historic Places. Such sites must have demonstrated importance in contributing to our understanding of local, regional, or national culture and history.

II. Significant Impacts Without adequate knowledge about the location and condition of significant prehistoric and historical cultural resources at the proposed facility sites for the Millers and Millers/Tully Rivers Alternative, it is impossible to predict the effects of the alternative upon cultural resources. In general, however, it can be stated that, considering the size and scale of the construction required for the implementation of the Millers or Millers/Tully River Alternative, only a limited impact upon cultural resources is expected. This is true in part because the project area is located within a region that has a low density of archaeological sites.

6.70.4 Mitigation/Enhancement Measures If the Millers or Millers/Tully River Alternative is selected as the preferred alternative, an intensive archaeological survey should be conducted to locate and identify currently unrecorded cultural resources that may exist at the location of the proposed facility sites. Special attention should be given to locating prehistoric sites in areas adjacent to the Millers and Tully Rivers, and at the outlet site in the Quabbin Reservoir.

BIBLIOGRAPHY

Dincauze, Dena et al. 1976
Cultural Resource Survey and Impact Evaluation Report. State Route 2: Greenfiled, Gill, Erving, Wendell, Orange, Franklin County, Massachusetts.

MHC 1982a
MHC Reconnaissance Survey Report: New Salem, Massachusetts. (Massachusetts Historical Commission).

MHC 1982b
MHC Reconnaissance Survey Report: Wendell, Massachusetts. (Massachusetts Historical Commission).

MHC Files
Prehistoric Site Files of the Massachusetts Historical Commission, Boston, Massachusetts.

Appendices

TABLE OF CONTENTS

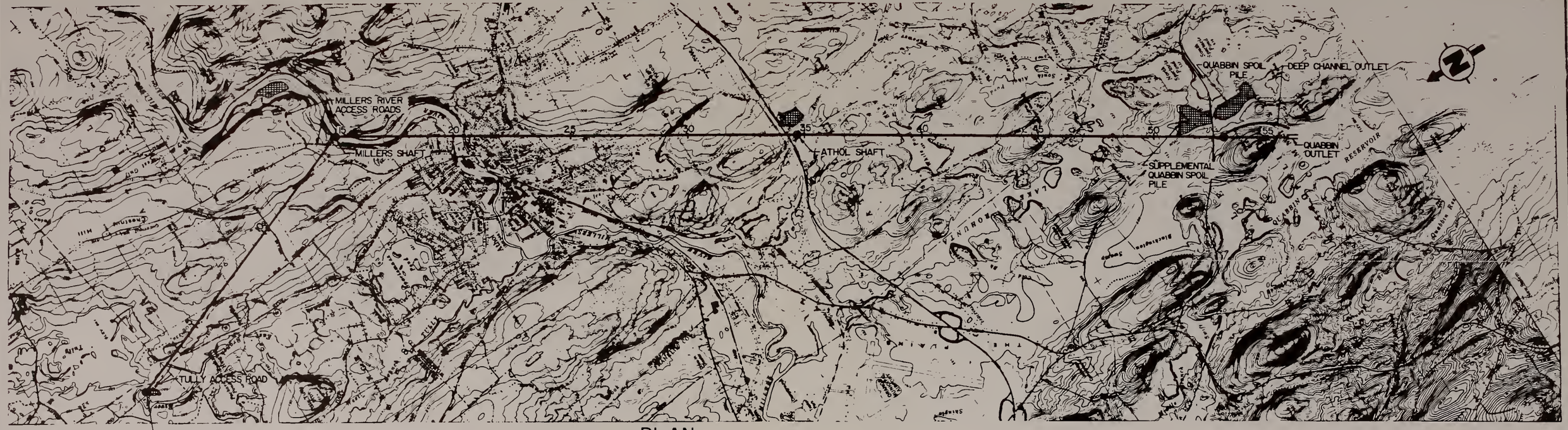
APPENDICES

	Page	
Appendix 6-1	A-1	Engineering Drawings
Appendix 6-2	A-13	Engineering Cost Calculations
Appendix 6-3	A-43	Unit Cost Calculations
Appendix 6-4	A-49	Hydrodynamic Diversion Simulations for Quabbin Reservoir
Appendix 6-5	A-65	Technical Appendix on Water Quality and Ecology for Task 6: Millers and Tully Rivers Alternative, Published Under Separate Cover; Prepared by New England Research, Inc., Volume I - Volume IV
Appendix 6-6	A-67	Technical Appendix on Water Quality for Task 6: Millers and Tully Rivers Alternative, Published Under Separate Cover; Prepared by Normandeau Associates, Inc.
Appendix 6-7	A-69	Technical Appendix on Aquatic Ecology for Task 6: Millers/Tully Rivers Alternative, Published Under Separate Cover; Prepared by Normandeau Associates, Inc.
Appendix 6-8	A-71	Technical Appendix on Terrestrial Ecology for Task 6: Millers/Tully Rivers Alternative, Published Under Separate Cover; Prepared by Normandeau Associates, Inc.

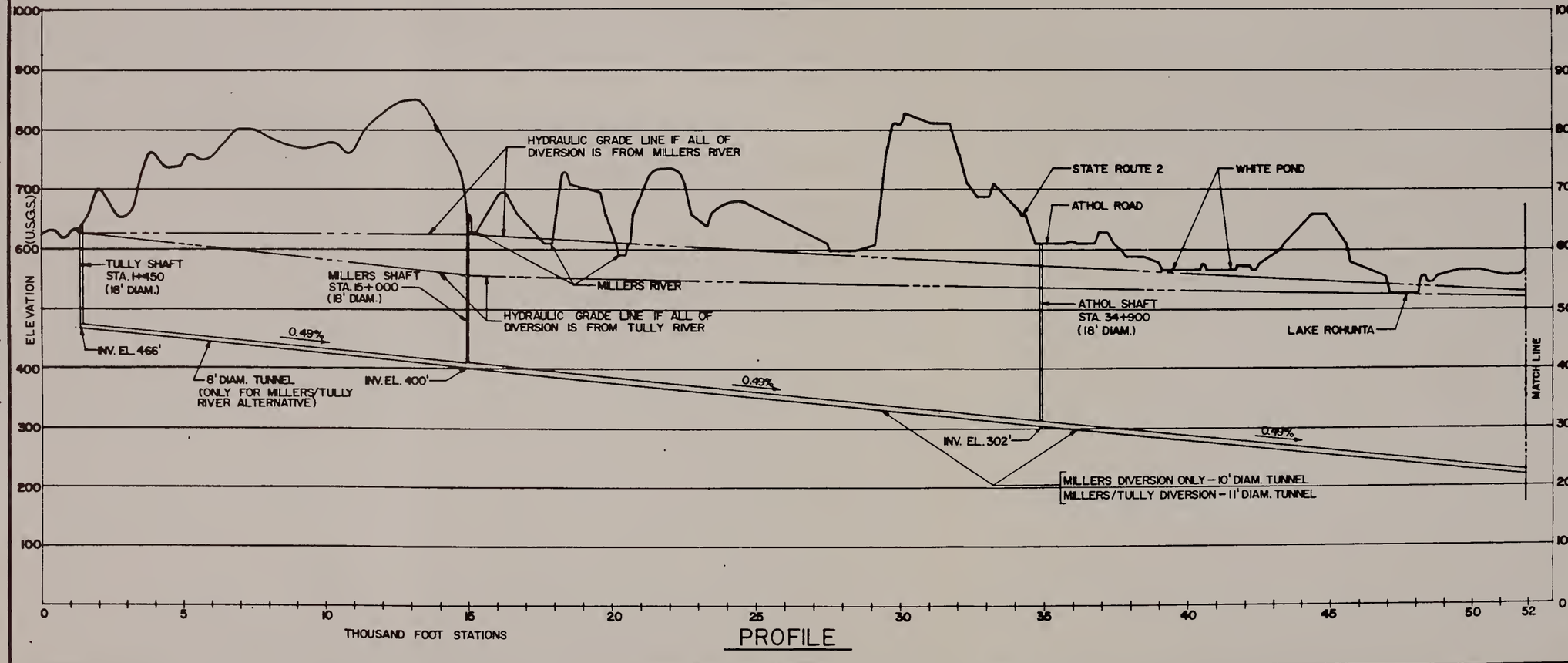
APPENDIX 6-1

ENGINEERING DRAWINGS

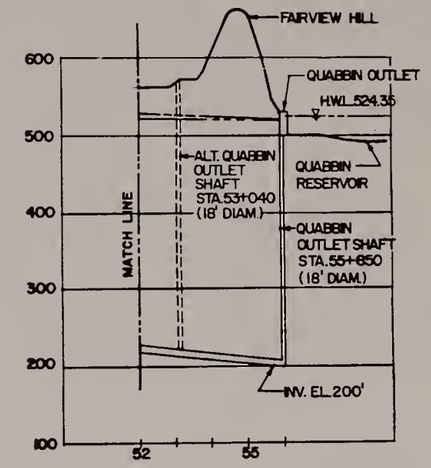
This drawing and the design it covers are the property of BECHTEL. They are not to be copied, used, loaned, exhibited, nor used except in the limited way and private reproduced, copied, loaned, exhibited, nor used except in the limited way and private use permitted by any written consent given by the holder to the borrower.



PLAN
SCALE 1 : 25,000



PROFILE



NO	DATE	REVISION	BY	CHK	APP
1	2/28/85	ISSUED WITH FINAL REPORT	JR		
0	4/24/84	ISSUED WITH DRAFT REPORT	JR		

SCALE NOTED | DATE 1-25-84 | DESIGNED JLR | DRAWN CZ

BECHTEL
GAITHERSBURG, MARYLAND

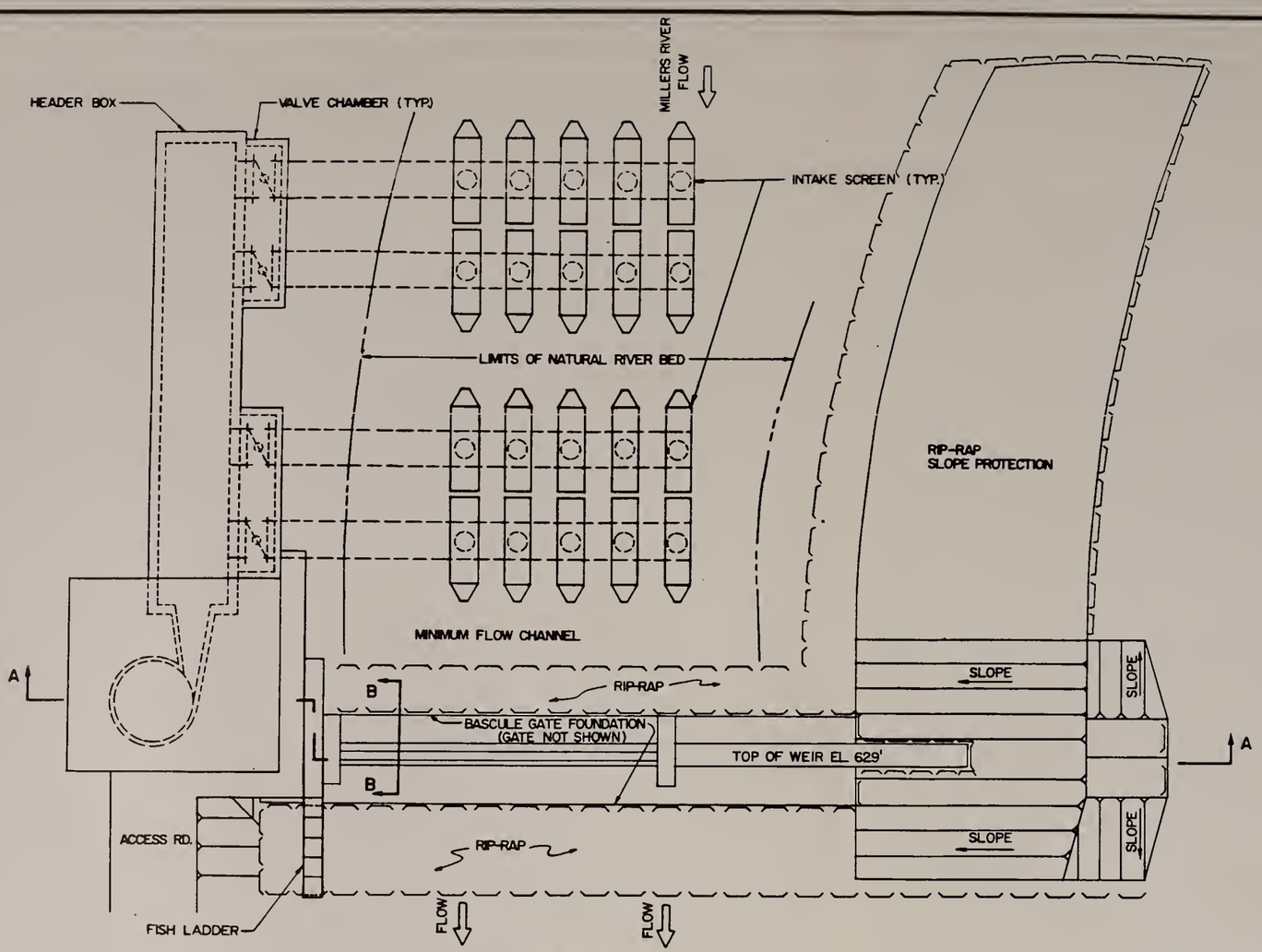
MDC WATER SUPPLY STUDY & EIR

MILLERS/TULLY RIVER ALTERNATIVE
PLAN AND PROFILE

JOB No.	DRAWING No.	REV.
15322	SK-T-001	1

22 x 34

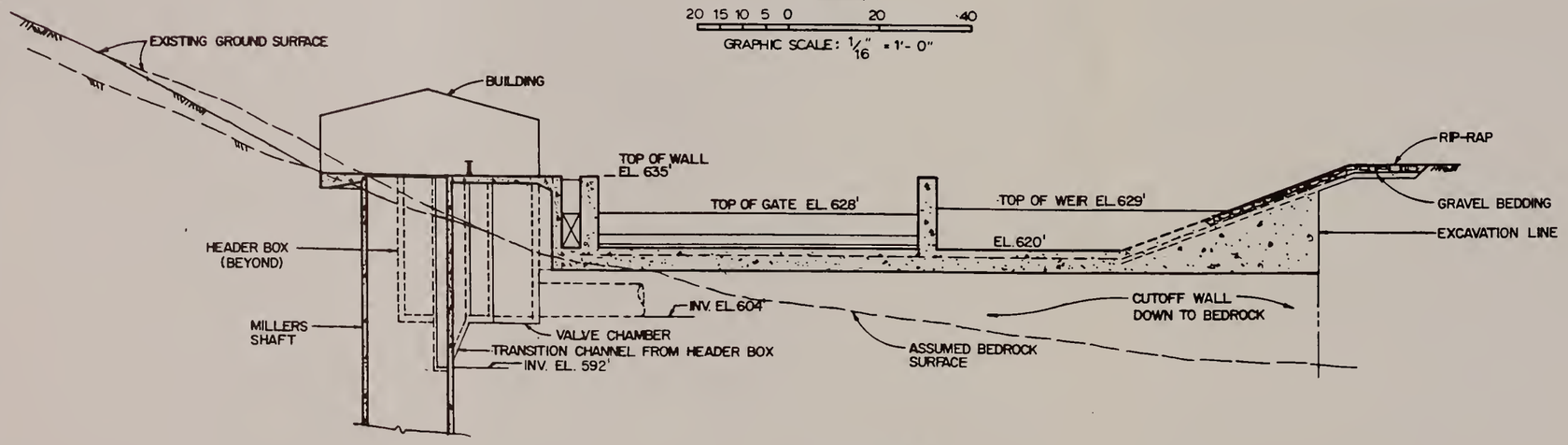
This drawing and the design it covers are the property of BECHTEL. They are merely loaned and on the borrower's express agreement that they will not be reproduced, copied, loaned, exhibited, nor used except in the limited way and private use permitted by any written consent given by the lender to the borrower.



PLAN

20 15 10 5 0 20 40

GRAPHIC SCALE: 1/16" = 1'-0"



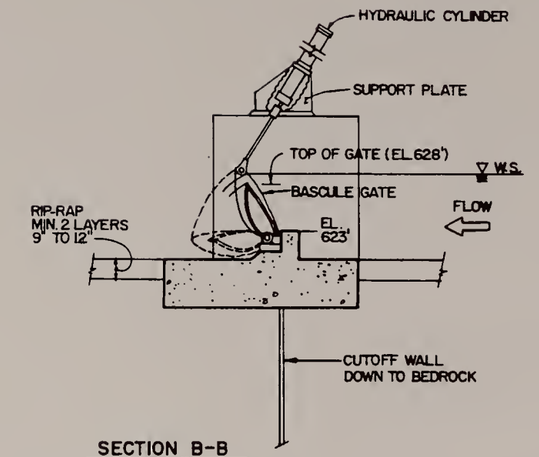
SECTION A-A

20 15 10 5 0 20 40

GRAPHIC SCALE 1/16" = 1'-0"

NOTES:

1. THE INTAKE SCREEN ARRANGEMENT IS APPROXIMATE, BASED ON INFORMATION PROVIDED BY SCREEN SUPPLIERS. PHYSICAL MODEL STUDIES WILL BE NECESSARY TO VERIFY LAYOUT, ALIGNMENT AND SPACING OF SCREENS AND PIPING.
2. ELEVATIONS REFER TO U.S.G.S. DATUM.



SECTION B-B

10 8 6 4 2 0 10 20

GRAPHIC SCALE: 1/8" = 1'-0"

NO.	DATE	REVISIONS	BY	CHKD	ENGR. MGR.	CHIEF ENGR.	PROJ. ENGR.	APPR.
1	4/26/85	ISSUED WITH FINAL REPORT	JLR	FSO				
0	9/20/84	ISSUED WITH DRAFT REPORT	JLR					

SCALE NOTED | DATE 1-25-84 | DESIGNED JLR | DRAWN CZ | CHIEF ENGR.

BECHTEL
GAITHERSBURG, MARYLAND

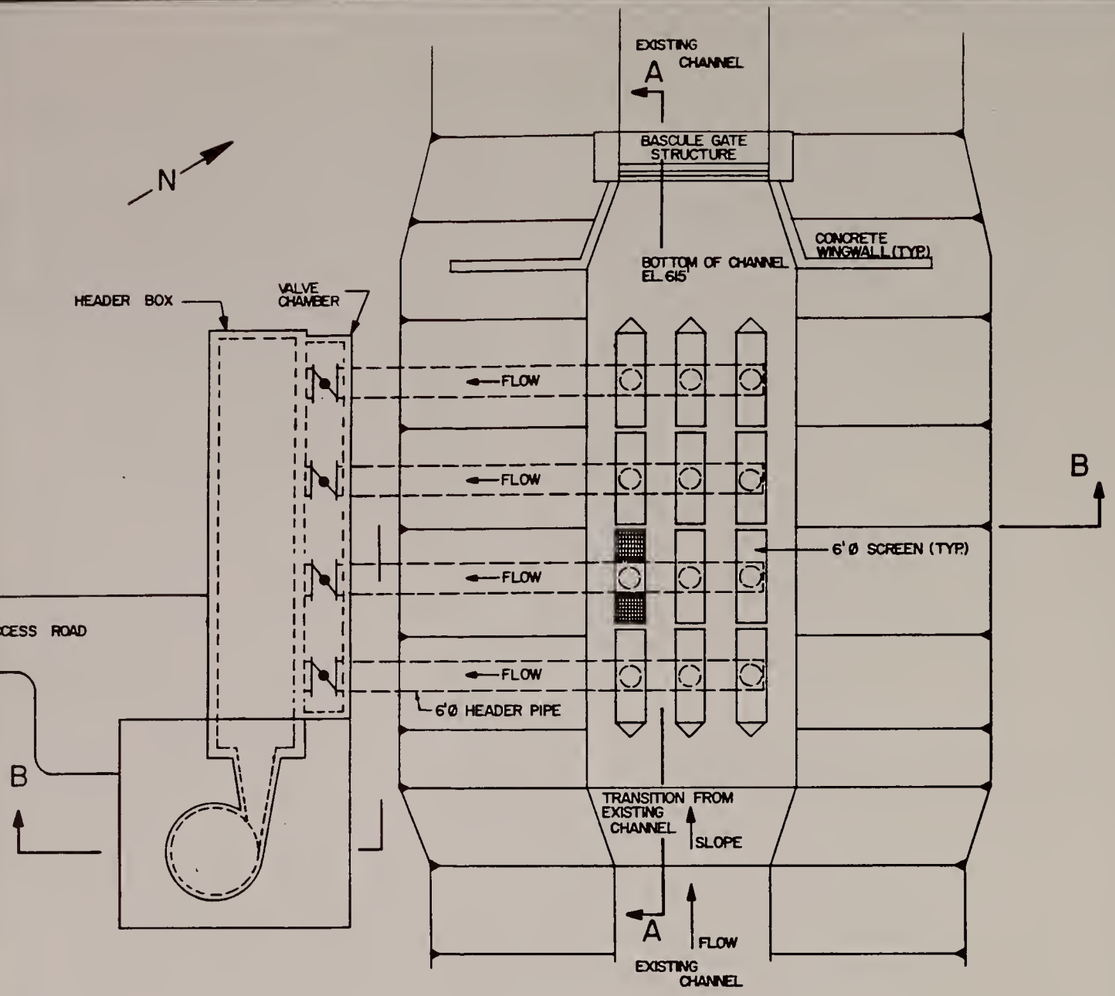
MDC WATER SUPPLY STUDY & EIR

MILLERS/TULLY RIVER ALTERNATIVE
MILLERS RIVER INTAKE

JOB No.	DRAWING No.	REV.
15322	SK-T-002	1

22 x 34 "D" SIZE

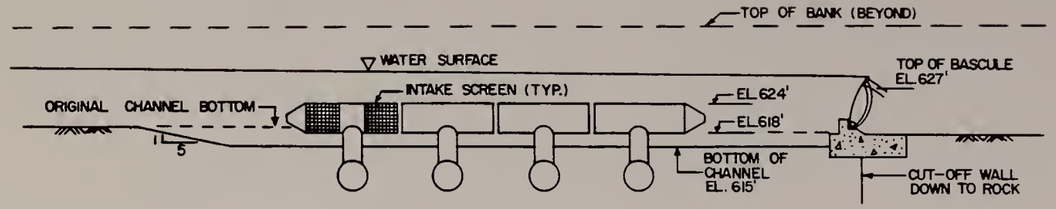
This drawing and the design it covers are the property of BECHTEL. They are merely loaned and on the borrower's express agreement that they will not be reproduced, copied, loaned, exhibited, nor used except in the limited way and private use permitted by any written consent given by the lender to the borrower.



PLAN

20 15 10 5 0 20 40

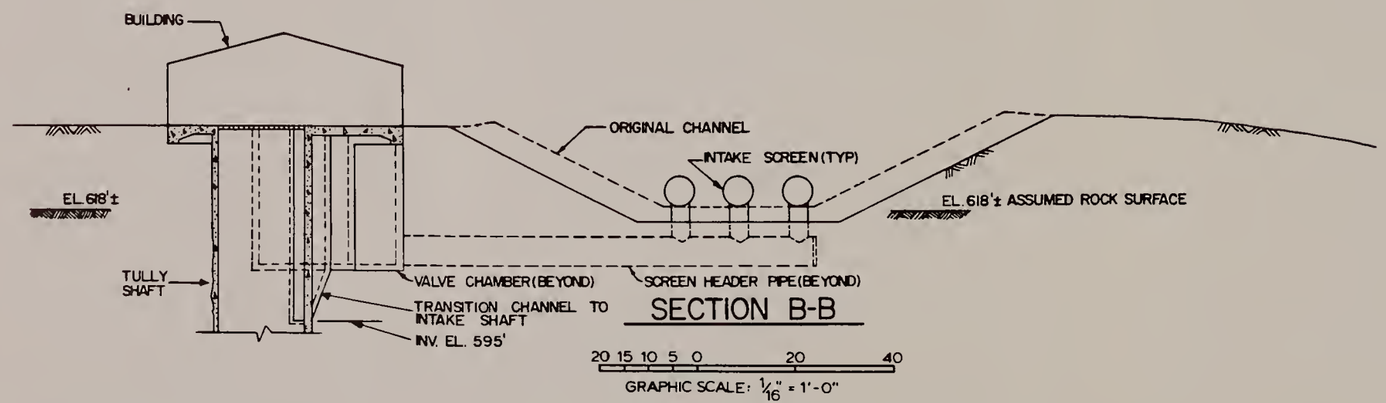
GRAPHIC SCALE: 1/16" = 1'-0"



SECTION A-A

20 15 10 5 0 20 40

GRAPHIC SCALE: 1/16" = 1'-0"



SECTION B-B

20 15 10 5 0 20 40

GRAPHIC SCALE: 1/16" = 1'-0"

NOTES:

1. THE INTAKE SCREEN ARRANGEMENT IS APPROXIMATE, BASED ON INFORMATION PROVIDED BY SCREEN SUPPLIERS. PHYSICAL MODEL STUDIES WILL BE NECESSARY TO VERIFY LAYOUT ALIGNMENT AND SPACING OF SCREENS AND PIPING.
2. ELEVATIONS REFER TO U.S.G.S. DATUM.

NO	DATE	REVISIONS	BY	CHKD	ENGR MGR	ENGR	PROJ ENGR	APPR
1	9/28/85	ISSUED WITH FINAL REPORT	JR	JLR			JLR	
0	4/20/84	ISSUED FOR DRAFT REPORT	JR	JLR			JLR	

SCALE NOTED | DATE 4-3-84 | DESIGNED J L R | DRAWN C Z | CHIEF ENGR.

BECHTEL
GAITHERSBURG, MARYLAND

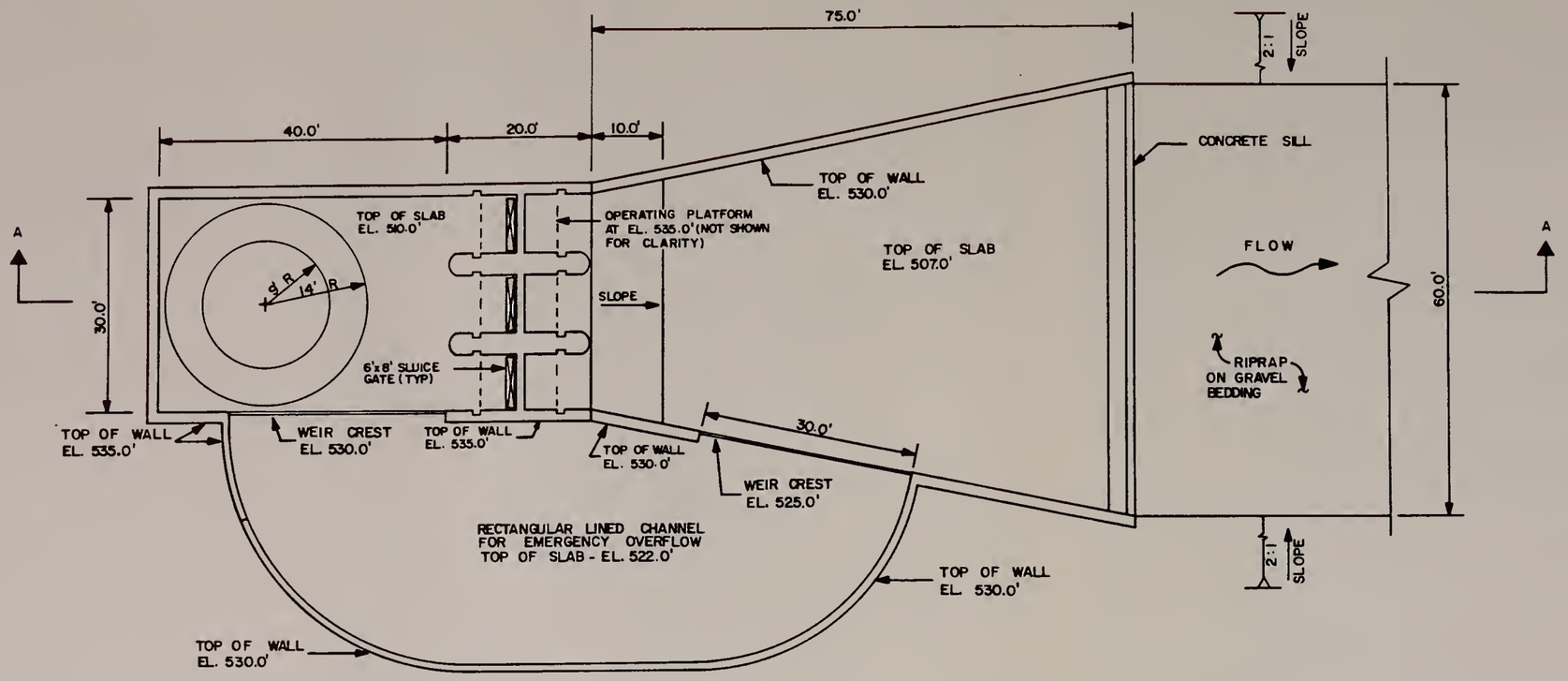
MDC WATER SUPPLY STUDY & EIR

MILLERS/TULLY RIVER ALTERNATIVE
TULLY LAKE INTAKE

JOB No.	DRAWING No.	REV.
15322	SK-T-003	1

22 x 34 "D" SIZE

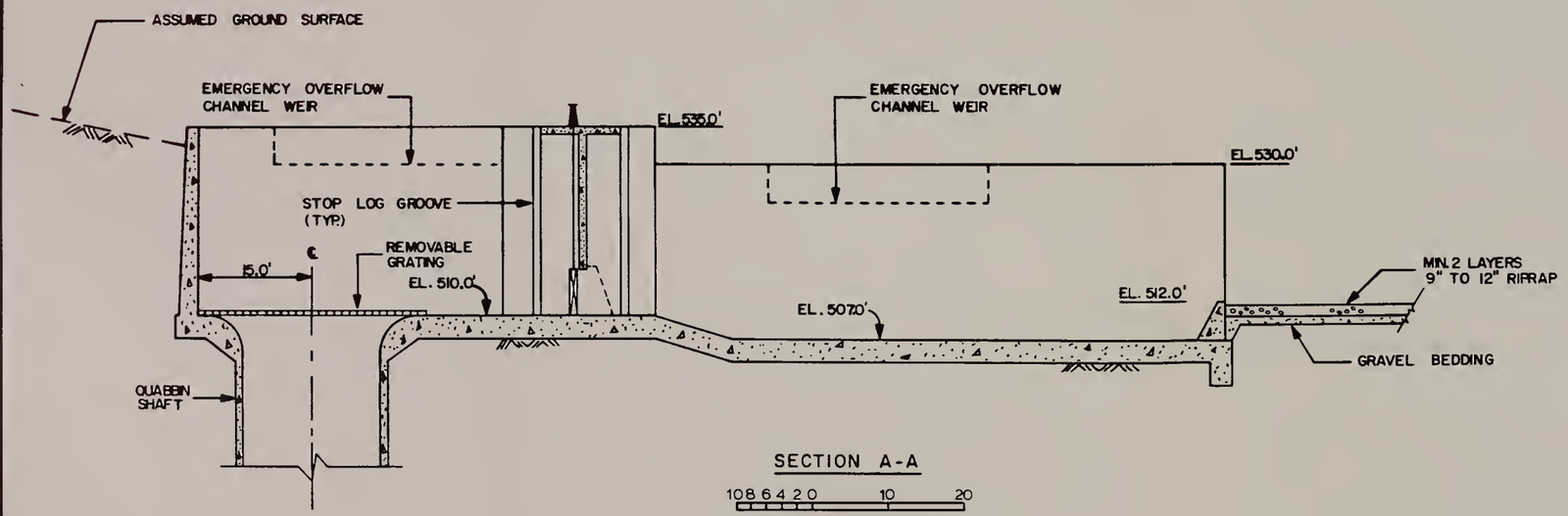
This drawing and the design it covers are the property of BECHTEL. They are merely loaned and on the borrower's express agreement that they will not be reproduced, copied, loaned, exhibited, nor used except in the limited way and private use permitted by any written consent given by the lender to the borrower.



PLAN

1 0 8 6 4 2 0 10 20

GRAPHIC SCALE : 1"= 10.0'



SECTION A-A

1 0 8 6 4 2 0 10 20

GRAPHIC SCALE : 1"= 10.0'

NOTES

1. ELEVATIONS REFER TO U.S.G.S. DATUM.

NO	DATE	REVISIONS	BY	CHKD	DESIGN SUPV	ENGR	PROJ ENGR	APPR
1	2/22/85	ISSUED WITH FINAL REPORT	JR	JRR			JRR	
0	4/20/84	ISSUED WITH DRAFT REPORT	JR	JRR			JRR	

SCALE NOTED | DATE 4-4-84 | DESIGNED J.R. | DRAWN M.P. | CHIEF ENGR. ——

BECHTEL
GAITHERSBURG, MARYLAND

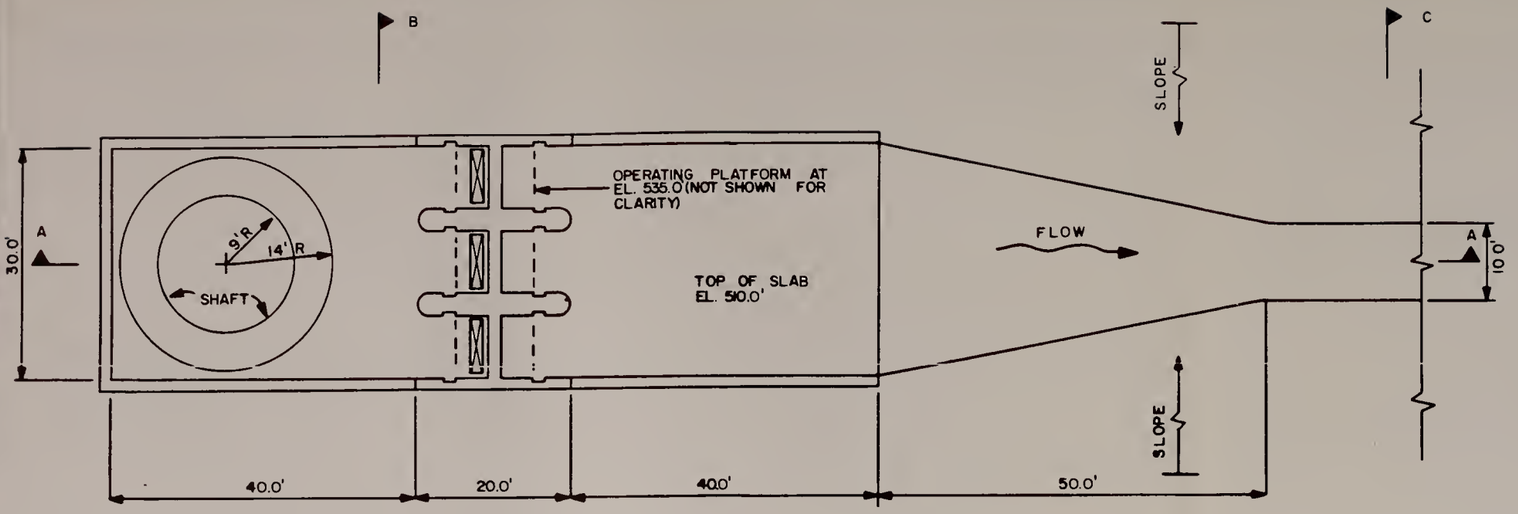
MDC WATER SUPPLY STUDY & EIR

MILLERS/TULLY RIVER ALTERNATIVE
DIRECT TUNNEL OUTLET

JOB No.	DRAWING No.	REV.
15322	SK-T-004	1

22 x 34 "D" SIZE

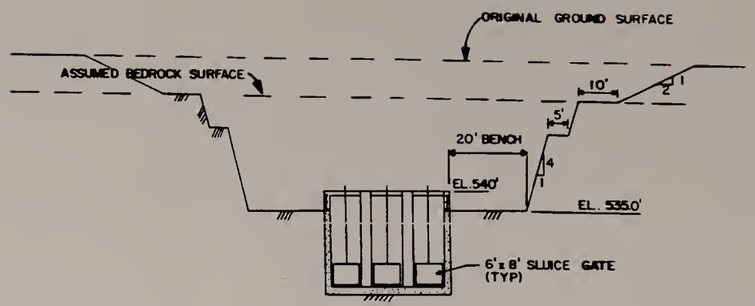
This drawing and the design it covers are the property of BECHTEL. They are merely loaned and on the borrower's express agreement that they will not be reproduced, copied, loaned, exhibited, nor used except in the limited way and private use permitted by any written consent given by the lender to the borrower.



PLAN

10 8 6 4 2 0 10 20

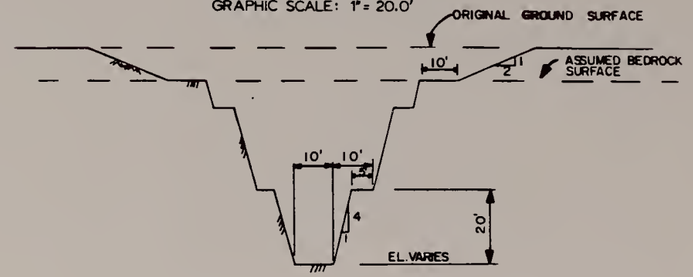
GRAPHIC SCALE: 1" = 10.0'



SECTION B-B

20 15 10 5 0 20 40

GRAPHIC SCALE: 1" = 20.0'



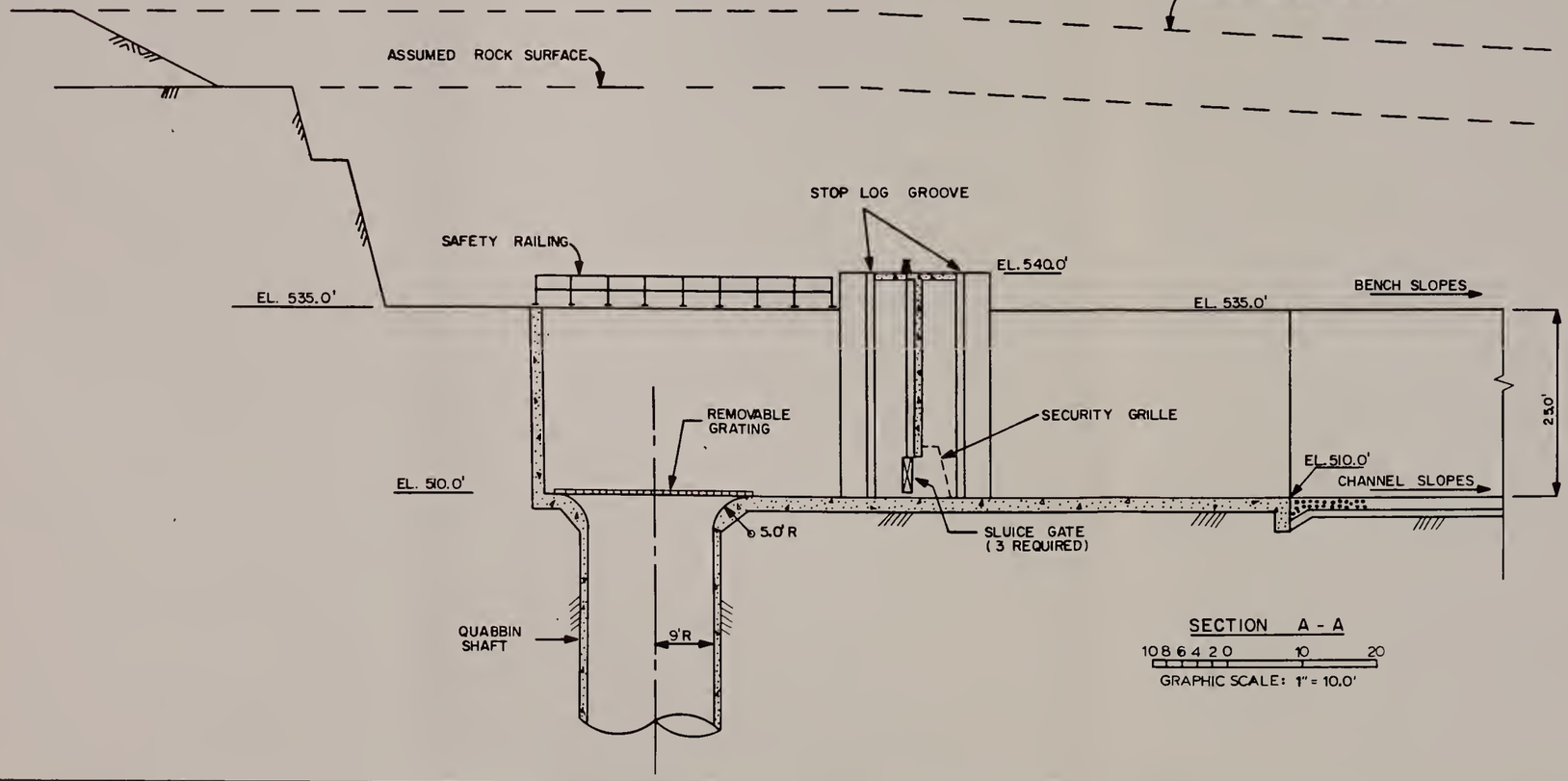
SECTION C-C

20 15 10 5 0 20 40

GRAPHIC SCALE: 1" = 20.0'

NOTES:

1. 5' BENCH EVERY 20' ELEV. DIFFERENCE IN ROCK CUT.
2. 10' BENCH EVERY 20' ELEV. DIFFERENCE IN SOIL CUT AND AT SOIL/ROCK INTERFACE.
3. ELEVATIONS REFER TO U.S.G.S. DATUM.



SECTION A - A

10 8 6 4 2 0 10 20

GRAPHIC SCALE: 1" = 10.0'

NO.	DATE	REVISIONS	BY	CHKD	ENGR MGR	PROJ ENGR	APPD
1	9/26/85	ISSUED WITH FINAL REPORT	JR	TJH		TJH	
0	4/20/84	ISSUED WITH DRAFT REPORT	JR	TJH		TJH	

SCALE NOTED | DATE 3-30-84 | DESIGNED J.R. | DRAWN M.P. | CHIEF ENGR. ——

BECHTEL
GAITHERSBURG, MARYLAND

MDC WATER SUPPLY STUDY & EIR

MILLERS/TULLY RIVER ALTERNATIVE
DEEP CHANNEL OUTLET

JOB No.	DRAWING No.	REV.
15322	SK-T-005	1

22 x 34 "D" SIZE

APPENDIX 6-2

ENGINEERING COST CALCULATIONS

ESTIMATE SUMMARY

KIM H
PREPARED BY

F. W. Matchner
CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

rev. 2 4/16/84 FM
rev. 1 4/11/84

15?-2-006
JOB NO.

Apvd 3.1984
DATE

SHEET 1 OF 11

MDC WATER SUPPLY - Millers River Alternate
PROJECT

10'-0" ϕ ID TBM Tunnel w/ Direct Outlet
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	MILLERS RIVER INTAKE	1	LS			4550000	
	SHAFTS w/ Reinf. Conc. Lining						
	Millers River 18'ϕ ID	260	LF	4000	1040000 ✓		@ Sta. 15+000
	Athol 18'ϕ ID	310	LF	4000	1240000 ✓		@ Sta. 34+900
	Quabbin Outlet 18'ϕ ID	300	LF	4000	1200000 ✓		@ Sta. 55+850
	total shafts					3480,000 ✓	
	TUNNEL w/ Reinf. Conc. Lining						
	Tunnel TBM	40850	LF	1187 76	48520000		
	total Tunnel					48520000	
	DIRECT OUTLET	1	LS			1,300,000 ✓	
	SPOIL PILES & CONTR WORK AREA	1	LS			520,000	
	TOTAL CONSTRUCTION COST (Incl. Contr. Overhead & Profit)					58370000	

WMH
PREPARED BY

F.W. Matchner
CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

ESTIMATE SUMMARY

rev.1 4/11/84

15322-006
JOB NO.

April 3, 1984
DATE

SHEET 2 OF 11

MDC WATER SUPPLY - Millers River Alternate
PROJECT

10'-0" ϕ ID TBM tunnel w/Direct Outlet
~~PREPARED FOR~~

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	TOTAL CONSTRUCTION COST (July 1982 PRICING LEVEL)					$2,370,000	(From PREVIOUS PAGE)
	CONTINGENCY					3,760,000	15% of Total Cost Above
	ENGG & CONST MNGMT FEES					6,710,000	10% of TOTAL COST ABOVE
	LAND + RIGHT OF WAY COSTS					20,000	
	LEGAL, FISCAL + ADM. FEES					140,000	0.25% of TOTAL COST ABOVE
	INTEREST DURING CONSTRUCTION					9,260,000	12.5% of TOTAL COST ABOVE based on 2.5yr. Constr. Period
	TOTAL CAPITAL COST					$23,300,000	

ESTIMATE SUMMARY

J.K. JIRGES
PREPARED BY

CHECKED BY

ORDER OF MAGNITUDE
TYPE OF ESTIMATE

rev. 1 4/11/84

15322-006-
JOB NO.

3-29-84
DATE

SHEET 3 OF 11

M.D.C. WATER SUPPLY – Millers River & Tully Lake Alternates
PROJECT

MILLERS RIVER INTAKE
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	MILLER RIVER INTAKE SCREEN	20	EA	60000	1200,000 ✓		
	PIPING: SCREEN TO INTAKE STRUCTR	2.620	LF	247.71	649,000 ✓		(VARIOUS SIZES)
	INTAKE STRUCTURE EQUIPMENT	1	LS		1,188000		(VALVES, COUPLERS & RECEIVERS)
	CIVIL WORK · INTAKE STRUCT. PIPING						
	EXCAVATION ROCK	1400	CY	16.00	22400 ✓		
	SOIL	950	CY	6.00	5.700 ✓		
	BACKFILL	1250	CY	10.00	12500 ✓		
	CONCRETE	1100	CY	200.00	220,000 ✓		
	REINFORCING STEEL	80,000	LB	0.45	36000 ✓		
	MODIFICATION OF RIVER BED (CIVIL WORK)						
	EXCAVATION ROCK	–	–	–	–		(ASSUME EXCAVATION MTRL. COBBLE)
	" SOIL	1.450	CY	6.00	8.700 ✓		
	CONCRETE	820	CY	350.00	287.000 ✓		
	REINFORCING STEEL	120.000	LB	0.45	54,000 ✓		
	BACKFILL	330	CY	10.00	3300 ✓		
	BASCULE GATE 70' x 6'	1	EH	180,000	180,000 ✓		
	INTAKE STRUCTURE: CIVIL WORK						
	EXCAVATION ROCK	2070	CY	16.00	33120 ✓		
	SOIL	190	CY	6.00	1.140 ✓		
	BACKFILL (PARKING)	800	CY	10.00	8000 ✓		
	CONCRETE	1070	CY	350.00	374.500 ✓		
	REINFORCING STEEL	220.000	LB	0.45	99000 ✓		

A-17

HRCE CSE 523 (3-80)

J.L. JIRGE
PREPARED BY

CHECKED BY

ORDER OF MAGNITUDE
TYPE OF ESTIMATE

MILLERS RIVER INTAKE
PREPARED FOR

ESTIMATE SUMMARY

MDC WATER SUPPLY
PROJECT

15272-000-
JOB NO.

REV.1 4/11/84
3-29-84
DATE

SHEET 4 OF 11

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	MILLERS RIVER DIVERSION						
	RIPRAP 18"	230	CY	20.00	4600 ✓		
	GRAVEL 12"	150	CY	16.00	2400 ✓		
	RAIL ROAD BANK						
	RIPRAP 18"	670	CY	20.00	13400 ✓		
	GRAVEL 12"	450	CY.	16.00	7200 ✓		
	PRE ENGINEERED BUILDING 50'X50'	2500	SF	30.00	75000 ✓		
		1	EA				
	FLOW METRG & AUTOMATIC CONTROL OF DIVERSION & DOWNSTREAM RELEASE	1	LT		20000 ✓		
	Water Quality Monitoring Station	1	LT		40,000		
						4544,960	✓
					USE	4,550,000	✓

A-18

ESTIMATE SUMMARY

ADW
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

Rev. 1 4/11/84

15322-006
JOB NO.

2/26/84
DATE

SHEET 5 OF 11

MISC WATER SUPPLY
PROJECT

MILLERS RIVER INTAKE
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
1	MILLER RIVER INTAKE SCREEN	20	EA	60,000		1,200,000	-
2	PIPING						
	96" ϕ	500	LF	950		475,000	
	48" ϕ	120	LF	450		54,000	
	8" ϕ	2000	LF	60		120,000	
3	INTAKE STRUCTURE						
	A. VALVES						
	84" ϕ CONTROL	4	EA	218750		875000	
	8" ϕ	20	EA	3000		60,000	
	B. AIR COMPRESSOR 10 SCFM @ 100 PSIG	1	EA	3000		3000	
	C. AIR RECEIVERS 250 CF 100 PSIG	5	EA	10,000		50,000	
4	BASCULE GATE 70' x 5'	1	EA	180,000		180,000	
5	FLOW METERING & AUTOMATIC CONTROL OF DIVERSION & DOWNSTREAM RELEASE	1	LT	20,000		20,000	

A-19

WMH
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

SHAFTS

ESTIMATE SUMMARY

MDC WATER SUPPLY - Millers River +
PROJECT

Millers River/Tully Lake Alternatives
PREPARED FOR

1522-006
JOB NO.

April 2 1984
DATE

SHEET 6 OF 11

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	Tully 18'Ø ID						
	Excavation + Support	170	LF	3000	510,000		
	Reinf Concrete Lining	170	LF	1000	170000		
	total					$ 680,000 ✓	
	Millers River 18'Ø ID						
	Excavation + Support	260	LF	3000	780,000		
	Reinf Concrete Lining	260	LF	1000	260,000		
	total					1040000 ✓	
	Athol 18'Ø ID						
	Excavation + Support	310	LF	3000	930,000		
	Reinf. Concrete Lining	310	LF	1000	310,000		
	total					1240000 ✓	
	Alt. Quabbin Outlet 18'ØID						
	Excavation + Support	360	LF	3000	1080000		
	Reinf Concrete Lining	360	LF	1000	360000		
	total					1440000 ✓	
	Quabbin Outlet 18'ØID						
	Excavation + Support	300	LF	3000	900,000		
	Reinf. Concrete Lining	300	LF	1000	300,000		
	total					1,200,000 ✓	

ESTIMATE SUMMARY

WMH
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

MDC WATER SUPPLY - Millers River Alternate
PROJECT

10'-0"Φ ID TBM TUNNEL
~~PREPARED FOR~~

15322-006
JOB NO.

April 2, 1984
DATE

SHEET 7 OF 11

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	T.B.M tunnel Excavation	40850	LF	790	32,271,500 ✓		
	Rock Bolts 3/4"Φ 5' long	109250	LF	10	1092500		
	Steel Sets W/Lagging	750	EA	600	450,000 ✓		
	Reinf. Concrete Lining	40850	LF	360	14706000 ✓		
						48520,000 ✓	

A-21

H&CE CSF 523 (3-80)

ESTIMATE SUMMARY

J.K. JIRGE
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

MDC WATER SUPPLY - Millers River +
PROJECT

Millers River/Hully Lake Alternates
PREPARED FOR

15322-006
JOB NO.

MARCH 29, 84
DATE

DIRECT OUTLET ALTERNATE I

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	OUTLET STRUCTURE						
	EXCAVATION SUPPORT	9,750	SF	21.50	209,625 ✓		
	COMMON EXCAVATION (WET)	11,000	CY	6.00	66,000 ✓		
	CONCRETE	1,640	CY	350.00	574,000 ✓		
	REINFORCING STEEL	260,000	lb	0.45	117,000 ✓		
	GRAVEL WORKING MAT (12" THICK)	9,200	SF	0.50	4 600 ✓		
	SLUICE GATE 6'x8' (MOTOR OPERATED)	3	EA	36,000.00	108,000 ✓		
	STOP LOGS, STEEL PANELS (6 ROWS - 9'x25')	1,350	SF	100.00	135,000 ✓		
	10 TON LIFTING CRANE (JIB MOUNTED)	2	EA	15,000.00	30,000 ✓		
	DIESEL-GEN W/ENCLOSURE	1	EA	30,000.00	30000 ✓		
	RIPRAP LINED CHANNEL						
	EXCAVATION	-	-	-	-		INCLUDED IN EXCAV. FOR OUTLET STRUCT.
	RIPRAP (18" THICK)	750	CY	20.00	15,000 ✓		
	GRAVEL (12" THICK)	490	CY	16.00	7,840 ✓		
	TOTAL					1297065 ✓	
					use	1300,000	

Job # 15322-006 MDC Water Supply

Millers River Alt. w/ Direct Outlet

TBM tunnels

Spoil Piles + Construction Work Areas

	Qty	Unit	Unit Price	Total
Clearing + Grubbing	56	Acres	750	42000
Placing + Compacting Spoil	320,000	cy	1.00	320,000
Revegetation	20	Acres	1000	20,000
				382000
+ Construction Access Roads	5600' (2 EA)			133,000
				515,000
			Use	520,000

Placing + Compacting Spoil

Millers River	9	140cy
Athol	144	440cy
Quabbin Reservoir - Direct Outlet	162	480cy
	316	060 cy

Use 320,000 cy

Construction Access Roads

Clearing 40' x 5000'/43560	4.6	Acre	750	3450
Gravel	3750	cy	16	60,000
Excavation	11,230	cy	6	67380
Fill	1230	cy	2	2460
				133,290
			Use	133,000

501 (6/81)

ESTIMATE SUMMARY

J.I. JIRIK
PREPARED BY

CHECKED BY

ORDER OF MAGNITUDE
TYPE OF ESTIMATE

DEEP CHANNEL OUTLET

MDC WATER SUPPLY - MILLERS RIVER &
PROJECT

Millers River/Tully Lake Alternates
PREPARED FOR

15302-116
JOB NO.

MARCH 20, 1981
DATE

SHEET 10 OF 11

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	OUTLET STRUCTURE						
	• EXCAVATION SUPPORT	-	-				(NOT REQUIRED)
	ROCK EXCAVATION	4,700	CY	16.00	75,200 ✓		
	GRAVEL WORKING MAT	4,200	SF.	0.50	2,100 ✓		
	CONCRETE	1,120	CY.	350.00	392,000 ✓		
	REINFORCING STEEL	170,000	lb	0.45	76,500 ✓		
	SLUICE GATES 6'x8'	3	EA	36000.00	108,000 ✓		
	STOP LOGS, STEEL PANELS (6 ROWS - 9'x25')	1,350	SF	100.00	135,000 ✓		
	10 TON LIFTING CRANES (JIB MOUNTED)	2	EA	15,000.00	30,000 ✓		
	DIESEL-GENERATOR W/ ENCLOSURE	1	EA	30,000.00	30,000 ✓		
	• CHANNEL						
	EXCAVATION ROCK	112,075	CY	9.00	1,008,675 ✓		
	" SOIL	96,160	CY	6.00	576,960 ✓		
	" COMMON (ASSUME)	3,100	CY	6.00	18,600 ✓		(DEPRESSION IN RESERVOIR)
	RIP RAP (18" THICK)	1,300	CY	20.00	26,000 ✓		
	GRAVEL (12" THICK)	850	CY	16.00	13,600 ✓		
	TOTAL					2492635 ✓	
					USE	2,500,000	

ESTIMATE SUMMARY

Wmkk
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

15322-006
JOB NO.

Rev.1 4/11/84 April 3, 1984
DATE

MDC WATER SUPPLY - Millers River Alternate
PROJECT

SHEET 11 OF 11

TBM tunnels - Comparison of Outlet Structures
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	DIRECT OUTLET						
	Quabbin Outlet Shaft	300	LF	4000	12,00,000		@ Sta. 55+850
	Tunnel TBM 10'ϕ ID	2810	LF	1187	3,337,600		Sta 53+040 to Sta 55+850
	Outlet Structure	1	LS		1,300,000		
					use	5837,600	
						5,840,000	
	DEEP CHANNEL OUTLET						
	Alt. Quabbin Outlet Shaft	360	LF	4000	1,440,000		@ Sta. 53+040
	Outlet Structure	1	LS		2500,000		
	Additional Clearing	23	Acre	750	17250		
	PLACING & COMPACTING Str	186,900	C.Y.	1.00	186,900	4,144,150	
					use	4,150,000	

A-25

USCE CSE 523 (3-80)

ESTIMATE SUMMARY

WJMH
PREPARED BY

F.W. Matchner
CHECKED BY

Order of magnitude
TYPE OF ESTIMATE

rev. 2 4/16/84 dr — 15322-006
rev. 1 4/11/84 — JOB NO

April 3, 1984
DATE

SHEET 1 OF 14

MDC WATER SUPPLY – Millers River/Tully Lake Alternate
PROJECT

8'-0" Ø ID & 11'-0" ID TBM tunnels w/Direct Outlet
~~PREPARED FOR~~

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	MILLERS RIVER INTAKE	1	LS		4,550,000		
	TULLY LAKE INTAKE	1	LS		2950,000		
	total Intakes					7500,000	
	SHAFTS w/Reinf Conc. Lining						
	Tully 18'Ø ID	170	LF	4000	680,000		℄ Sta. 1+456
	Millers River 18'Ø ID	260	LF	4000	1040,000		℄ Sta 15+000
	Athol 18'Ø ID	310	LF	4000	1240,000		℄ Sta 34+900
	Quabbin Outlet 18'Ø ID	300	LF	4000	1200000		℄ Sta 55+850
	total shafts					4160,000	
	TUNNELS w/Reinf. Conc Lining						
	tunnel TBM 8'Ø ID	13550	LF	1042.00	14,120,000		
	tunnel TBM 11'Ø ID	40850	LF	1250.61	51,090,000		
	total tunnels					65,210,000	
	DIRECT OUTLET	1	LS			1,300,000	
	SPOIL PILES + CONTR. WORK AREA	1	LS			680,000	
	TOTAL CONSTRUCTION COST (incl. Contr. Overhead + Profit)					78,450,000	

(USCE-CSE 5-23 (2-80)

ESTIMATE SUMMARY

WMH
PREPARED BY

F. W. Matchmer
CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

15372-006
JOB NO.

April 3, 1984
DATE

SHEET 2 OF 14

MDC WATER SUPPLY - Millers River/Tully Lake Alternate
PROJECT

8'-0" ⌀ ID + 11'-0" ID TBM tunnels w/ Direct Outlet
~~PREPARED FOR~~

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	TOTAL CONSTRUCTION COST (July 1982 PRICING LEVEL)					78,850,000	FROM PREVIOUS PAGE
	CONTINGENCY					11,830,000	15% of TOTAL COST ABOVE
	ENGG + CONST MNGMT FEES					9,070,000	10% of TOTAL COST ABOVE
	LAND + RIGHT OF WAY COSTS					30,000	
	LEGAL, FISCAL + ADM. FEES					250,000	0.25% of TOTAL COST ABOVE
	INTEREST DURING CONSTRUCTION					12,500,000	12.5% of TOTAL COST ABOVE based on 2.5 yr. Constr. Period
	TOTAL CAPITAL COST					112,530,000	

A-27

H&CF CSE 523 (3-80)

J.K. JIRGE
PREPARED BY

CHECKED BY

ORDER OF MAGNITUDE
TYPE OF ESTIMATE

ESTIMATE SUMMARY

rev.1 4/11/84

M.D.C. WATER SUPPLY – Millers River & Tully Lake Alternates
PROJECT

MILLERS RIVER INTAKE
PREPARED FOR

15322-006
JOB NO.

3-29-84
DATE

SHEET 3 OF 14

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	MILLER RIVER INTAKE SCREEN	20	EA	60000	1200,000 ✓		
	PIPING: SCREEN TO INTAKE STRUCT'R	2.620	LF	247.71	649,000 ✓		(VARIOUS SIZES)
	INTAKE STRUCTURE EQUIPMENT	1	LS		1,188000		(VALVES, CHILLERS & RECEIVERS)
	CIVIL WORK · INTAKE STRUCT. PIPING						
	EXCAVATION ROCK	1400	CY	16.00	22400 ✓		
	SOIL	950	CY	6.00	5.700 ✓		
	BACKFILL	1250	CY	10.00	12500 ✓		
	CONCRETE	1100	CY	200.00	220,000 ✓		
	REINFORCING STEEL	80,000	LB	0.45	36000 ✓		
	MODIFICATION OF RIVER BED (CIVIL WORK)						
	EXCAVATION ROCK	–	–	–	–		(ASSUME EXCAVATION MTRL CODDL
	" SOIL	1.450	CY	6.00	8.700 ✓		
	CONCRETE	820	CY	350.00	287.000 ✓		
	REINFORCING STEEL	120,000	LB	0.45	54,000 ✓		
	BACKFILL	330	CY	10.00	3300 ✓		
	BASCULE GATE 70' x 8'	1	EA	180,000	180,000 ✓		
	INTAKE STRUCTURE: CIVIL WORK						
	EXCAVATION ROCK	2070	CY	16.00	33120 ✓		
	SOIL	190	CY	6.00	1.140 ✓		
	BACKFILL (PACKING)	800	CY	10.00	8000 ✓		
	CONCRETE	1070	CY	350.00	374.500 ✓		
	REINFORCING STEEL	220,000	LB	0.45	99000 ✓		

ESTIMATE SUMMARY

J.E. JIRGE
PREPARED BY

CHECKED BY

ORDER OF MAGNITUDE
TYPE OF ESTIMATE

MDC WATER SUPPLY
PROJECT

MILLERS RIVER INTAKE
PREPARED FOR

15322-006.
JOB NO.

REV.1 4/11/84

3-29-84
DATE

SHEET 4 OF 14

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	MILLERS RIVER DIVERSION						
	RIPRAP 18"	230	CY	20.00	4600 ✓		
	GRAVEL 12"	150	CY	16.00	2400 ✓		
	RAILROAD BANK						
	RIPRAP 18"	670	CY	20.00	13400 ✓		
	GRAVEL 12"	450	CY.	16.00	7200 ✓		
	PRE ENGINEERED BUILDING	2500	SF	30.00	75000 ✓		
	50'X50'	1	EA				
	FLOW METRG & AUTOMATIC	1	LT		20000 ✓		
	CONTROL OF DIVERSION &						
	DOWNSTREAM RELEASE						
	Water Quality Monitoring	1	LT		40,000		
	Station					4544,960	✓
					L+P	4,550,000	✓

ESTIMATE SUMMARY

ADW
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

Rev.1 4/11/84

15322-006
JOB NO

3/26/84
DATE

SHEET 5 OF 14

MDC WATER SUPPLY
PROJECT

MILLERS RIVER INTAKE
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
1	MILLER RIVER INTAKE SCREEN	20	EA	60,000		1,200,000	-
2	PIPING						
	96" ϕ	500	LF	950		475,000	
	48" ϕ	120	LF	450		54,000	
	8" ϕ	2000	LF	60		120,000	
3	INTAKE STRUCTURE						
	A. VALVES						
	84" ϕ CONTROL	4	EA	218750		875000	
	8" ϕ	20	EA	3000		60,000	
	B. AIR COMPRESSOR 10 SCFM @ 100 PSIG	1	EA	3000		3000	
	C. AIR RELEASES 250 CF 100 PSIG	5	EA	10,000		50,000	
4	BASCULE GATE 70' x 5' H	1	EA	180,000		180,000	
5	FLOW METERING & AUTOMATIC CONTROL OF DIVERSION & DOWNSTREAM RELEASE	1	LT	20000		20,000	

A-30

ESTIMATE SUMMARY

J.K. JUDGE
PREPARED BY

CHECKED BY

ORDER OF MAGNITUDE
TYPE OF ESTIMATE

rev.1 4/11/84

15322-006
JOB NO.

3-29-84
DATE

SHEET 6 OF 14

M.D.C. WATER SUPPLY
PROJECT

TULLY LAKE INTAKE
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	TULLY INTAKE SCREENS	12	EA	60.000	720.000 ✓		
	PIPING TO INTAKE STRUCTURE	1722	LF	243.55	419.400 ✓		(VARIOUS SIZES)
	INTAKE STRUCTURE EQUIP.	1	LT		856,000.		(VALVES, CONTR & RECEIVERS)
	BASCULE GATE	1	EA	100.000	100.000 ✓		
	FLOW METRG & AUTO CONTROL OF DIVERSION & DOWNSTREAM RELEASE	1	LT		20.000 ✓		
	CIVIL WORK INTAKE PIPING:						
	EXCAVATION: ROCK	1400	CY	16.00	22400 ✓		
	" SOIL (COMMON)	820	CY	6.00	4920 ✓		
	CONCRETE	710	CY	200.00	142000		
	REINFORCING STEEL	70.000	LB	.45	31500 ✓		
	BACKFILL	1,120	CY	10.00	11200 ✓		
	CIVIL WORK: OUTLET CHANNEL						
	EXCAVATION ROCK	750	CY	16.00	12000 ✓		
	" SOIL	2700	CY	6.00	16,200 ✓		
	CONCRETE	250	CY	350.00	87500 ✓		
	REINFORCING STEEL	50.000	LB	0.45	22500 ✓		
	PRE ENGINEERED BLDG. 50X50	2500 (1	SF EA)	30.00	75000 ✓		

ESTIMATE SUMMARY

J.K. JIRGE
PREPARED BY

CHECKED BY

ORDER OF MAGNITUDE
TYPE OF ESTIMATE

15822.006
JOB NO.

Rev, 1 4/11/84 3-29-84
DATE

M.D.C WATER SUPPLY –
PROJECT

SHEET 7 OF 14

TULLY LAKE INTAKE
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	INTAKE STRUCTURE						
	EXCAVATION Rock	1410	CY	16.00	22560 ✓		
	" Soil	1570	CY	6.00	9,420 ✓		
	CONCRETE	820	CY	350.00	287,000 ✓		
	REINFORCING STEEL	164,000	LB	0.45	73,800 ✓		
	Water Control Monitoring Equipment	1	LT		10,000		
						2943400	
					use	2950,000	

A-32

ESTIMATE SUMMARY

ADW
PREPARED BY

CHECKED BY

order of magnitude
TYPE OF ESTIMATE

MDC WATER SUPPLY
PROJECT

TULLY LAKE INTAKE
PREPARED FOR

15722-006
JOB NO.

rev.1 4/11/84 3/26/83
DATE

SHEET 8 OF 14

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
1	TULLY INTAKE SCREEN 151000 ⓘ	12	EA	60,000		720,000	
2	PIPING:						
	72" ϕ	450	LF	700		315,000	
	48" ϕ	72	LF	450		32400	
	8" ϕ	1200	LF	60		72,000	
3	INTAKE STRUCTURE						
	A. VALVES						
	CONTROL VALVE 60" ϕ	4	EA	167000		668,000	
	8" ϕ VALVE	12	EA	3000		36,000	
	B. AIR COMPRESSOR 5 SCFM @ 100 PSIG	1	EA	2000		2000	
	C. AIR RECEIVERS 250 CF 100 PSIG	3	EA	10000		30000	
4	BASCULE GATE 30' x 5'	1	EA	100000		100,000	
5	FLOW METERING & AUTOMATIC CONTROL OF DIVERSION & DOWNSTREAM RELEASE	1	LT	20000		20,000	

A-33

H&CF CSE 523 (3-80)

WMH
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

SHAFTS

ESTIMATE SUMMARY

MDC WATER SUPPLY - Millers River +
PROJECT

Millers River/Tully Lake Alternatives
PREPARED FOR

15322-006
JOB NO.

April 2 1984
DATE

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	Tully 18'ØID						
	Excavation + Support	170	LF	3000	510,000		
	Reinf Concrete Lining	170	LF	1000	170000		
	total					# 680,000 ✓	
	Millers River 18'ØID						
	Excavation + Support	260	LF	3000	780,000		
	Reinf Concrete Lining	260	LF	1000	260,000		
	total					1040000 ✓	
	Athol 18'ØID						
	Excavation + Support	310	LF	3000	930,000		
	Reinf. Concrete Lining	310	LF	1000	310,000		
	total					1240000 ✓	
	All. Quabbin Outlet 18'ØID						
	Excavation + Support	360	LF	3000	1080000		
	Reinf Concrete Lining	360	LF	1000	360000		
	total					1440000 ✓	
	Quabbin Outlet 18'ØID						
	Excavation + Support	300	LF	3000	900,000		
	Reinf. Concrete Lining	300	LF	1000	300,000		
	total					1,200,000 ✓	

ESTIMATE SUMMARY

Kimth
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

15-22-006
JOB NO.

April 2, 1984
DATE

SHEET 10 OF 14

MDC WATER SUPPLY - Millers River/Tully Lake Alternate
PROJECT

8'-0" ID + 11'-0" ID TBM tunnels w/ Direct Outlet
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	TBM Tunnel 8'-0" ID						
	Excavation	13550	LF	720	9756000 ✓		
	Rock Bolts 3/4" ϕ 5' long	29800	LF	10	298000 ✓		
	Steel Sets w/ Lagging	—			—		
	Reinf. Concrete Lining	13550	LF	300	4065000 ✓		
	total 8'-0" ID tunnel					14119000 ✓	
	TBM Tunnel 11'-0" ID						
	Excavation	40850	LF	810	33085500 ✓		
	Rock Bolts 3/4" ϕ 5' long	117650	LF	10	1,176500 ✓		
	Steel Sets w/ Lagging	750	EA	650	487500 ✓		
	Reinf. Concrete Lining	40850	LF	400	16340,000 ✓		
	total 11'-0" ID tunnel					51089500 ✓	
	TOTAL					65,208500 ✓	
					Use $	65209,000	

A-35

USCE CSF 527 (3-80)

ESTIMATE SUMMARY

J.K. JIRGE
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

MDC WATER SUPPLY - Millers River +
PROJECT

Millers River/Hully Lake Alternates
~~PREPARED FOR~~

15322-006
JOB NO.

MARCH 29, 84
DATE

SHEET 11 OF 14

DIRECT OUTLET ALIGNMENT I

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	OUTLET STRUCTURE						
	EXCAVATION SUPPORT	9,750	SF	21.50	209,625 ✓		
	COMMON EXCAVATION (WET)	11,000	CY	6.00	66,000 ✓		
	CONCRETE	1,640	CY	350.00	574,000 ✓		
	REINFORCING STEEL	260,000	lb	0.45	117,000 ✓		
	GRAVEL WORKING MAT (12" THICK)	9,200	SF	0.50	4,600 ✓		
	SLUICE GATE 6'x8' (MOTOR OPERATED)	3	EA	36,000.00	108,000 ✓		
	STOP LOGS, STEEL PANELS (6 ROWS - 9'x25')	1,350	SF	100.00	135,000 ✓		
	10 TON LIFTING CRANE (JIB MOUNTED)	2	EA	15,000.00	30,000 ✓		
	DIESEL-GEN W/ENCLOSURE	1	EA	30,000.00	30,000 ✓		
	RIPRAP LINED CHANNEL						
	EXCAVATION	-	-	-	-		INCLUDED IN EXCAV. FOR OUTLET STRUCT.
	RIPRAP (12" THICK)	750	CY	20.00	15,000 ✓		
	GRAVEL (12" THICK)	490	CY	16.00	7,840 ✓		
	TOTAL					1297065 ✓	
					use	*1300,000	

A-36

Job # 15122-006 MDC Water Supply

Millers River/Tully Lake Alt. w/ Direct Outlet

TBM Tunnels

Spoil Piles + Construction Work Areas -

	Qty	Unit	Unit Price	Total
Clearing + Grubbing	71	Acres	750	54000
Placing + Compacting Spoil	450000	CY	1 00	450000
Revegetation	25	Acre	1000	25000
				529000
Construction Access Roads	5600' (3 EA)			144500
				673500
Placing + Compacting Spoil			LS	680,000
Tully	11 030 CY			
Millers River	73 870 CY			
Athol	168 800 CY			
Ginegbin Res. - Diversion Outlet	188 120 CY			
	441 820 CY			
	LS 450,000 CY			

Construction Access Roads

Millers River Alt. Roads					133,290
Tully Intake Road					
Clearing	40'X600'/43560	.55	Acre	750	410
Gravel		450	CY	16	7200
Excavation		450	CY	6	2700
Fill		450	CY	2	900
					144500

501(6/81)

ESTIMATE SUMMARY

J.K. JIGGS
PREPARED BY

CHECKED BY

ORDER OF MAGNITUDE.
TYPE OF ESTIMATE

DEEP CHANNEL OUTLET.

MDC WATER SUPPLY - MILLERS RIVER &
PROJECT

Millers River/Tully Lake Alternates
PREPARED FOR

1532C-006
JOB NO.

MARCH 29 '84
DATE

SHEET 13 OF 14

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	OUTLET STRUCTURE						
	• EXCAVATION SUPPORT	-	-				(NOT REQUIRED)
	ROCK EXCAVATION	4,700	CY	16.00	75,200 ✓		
	GRAVEL WORKING MAT	4,200	SF	0.50	2,100 ✓		
	CONCRETE	1,120	CY	350.00	392,000 ✓		
	REINFORCING STEEL	170,000	lb	0.45	76,500 ✓		
	SLUICE GATES 6'x8'	3	EA	36000.00	108,000 ✓		
	STOP LOGS, STEEL PANELS (6 ROWS - 9'x25')	1,350	SF	100.00	135,000 ✓		
	10 TON LIFTING CRANES (JIB MOUNTED)	2	EA	15,000.00	30,000 ✓		
	DIESEL-GENERATOR W/ ENCLOSURE	1	EA	30,000.00	30,000 ✓		
	• CHANNEL						
	EXCAVATION ROCK	112,075	CY	9.00	1,008,675 ✓		
	" SOIL	96,160	CY	6.00	576,960 ✓		
	" COMMON (ASSUM)	3,100	CY	6.00	18,600 ✓		(DIVERSION IN ELEVATION)
	RIP RAP (18" THICK)	1,300	CY	20.00	26,000 ✓		
	GRAVEL (12" THICK)	850	CY	16.00	13,600 ✓		
	TOTAL					2492635 ✓	
					USE	2,500,000	

ESTIMATE SUMMARY

VMH
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

Rev. 1 4/11/84

15322-005
JOB NO.

April 3, 1984
DATE

SHEET 14 OF 14

MDC WATER SUPPLY - Millers River/Tully Lake Alternate
PROJECT

TBM tunnels - Comparison of Outlet Structures
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	DIRECT OUTLET						
	Quabbin Outlet Shaft	300	LF	4000	1200000		℄ Sta 55+850
	Tunnel TBM 11'Ø ID	2810	LF	1250	3514400		
	Outlet Structure	1	LS		1300000		
						6014400	
					SAY	6,010,000	
	DEEP CHANNEL OUTLET						
	Alt. Quabbin Outlet Shaft	360	LF	4000	1,440,000		℄ Sta. 53+040
	Outlet Structure	1	LS		2500000		
	Additional Clearing	23	Acre	750	17250		
	PLACING & COMPACTING SPOIL	183,500	C.Y	1.00	183,500		
						4,140,750	
					SAY	4,140,000	

Bechtel Civil & Minerals, Inc.

15740 Shady Grove Road
Gaithersburg, Maryland 20877 - 1454
301-258-3000

RECEIVED
APR 17 1985
WALLACE, FLOYD, ASSOCIATES INC.

April 9, 1985
BLW:308
File: 3.6, 11.6

Ms. Helen R. Strieder
Wallace, Floyd, Associates Inc.
Russia Wharf
286 Congress Street
Boston, MA 02210

Dear Helen:

Subject: Bechtel Job 15322
MDC Water Supply Study and EIR
O&M Cost Estimates for Millers/Tully Alternative

On several of the engineering alternatives, the MDC has requested backup to the operating and maintenance (O&M) cost estimates. Since this backup was not specifically requested for the Millers/Tully Alternative, my colleagues did not include it with the final report on engineering and cost which was sent to you on March 4, 1985.

To make the Millers/Tully report complete and consistent with the reports on the other alternatives, we are transmitting, herewith, a copy of the O&M cost backup to be included in the final Millers/Tully report. I apologize for any inconvenience that this omission might have caused.

Very truly yours,

Frank Matchner

Frank W. Matchner III
Project Engineer

FWM:ad

Enclosure

ESTIMATING WORKSHEET

CLIENT MDC
PROJECT & LOCATION Millers River Diversion
PREPARED BY: dL Royall
CHECKED BY: F. Hatchner
SHEET 1 OF 2
DATE 4-16-84

CODE ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	OPERATING & MAINTENANCE COSTS $/YR ENERGY	$/YR Labor	$/YR MAT'L/CHEM.	$/YR TOTAL
	WATER QUALITY MONITORING STATION AT MILLERS R.				1500	23000	21000	45500
	MILLERS RIVER INTAKE				1200	124000	3000	128200
	TUNNEL & OUTLET STRUCTURE				800	3000	1000	4800
	TOTALS				3500	150000	25000	178500
				use	5000	150000	25000	180000

NOTE: THE ENERGY, LABOR, MATERIALS AND CHEMICAL COSTS ASSOCIATED WITH LABORATORY TESTING OF THE WATER SAMPLES HAVE BEEN INCLUDED UNDER THE ITEM - "WATER QUALITY MONITORING STATION AT MILLERS R."

GPD-13912 2/81

ESTIMATING WORKSHEET

CLIENT MDC
PROJECT & LOCATION Millers / Tully River Diversion
PREPARED BY: J L Royall
CHECKED BY: G. Matahner
SHEET 2 OF 2
DATE 4-16-84

CODE ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	OPERATING & MAINTENANCE COSTS ENERGY $/yr	LABOR $/yr	MAT'L/CHEM. $/yr	TOTAL $/yr
	WATER QUALITY MONITORING at Tully Dam				500	4000	3000	7500
	WATER QUALITY MONITORING STATION AT MILLERS R.				1500	23000	21000	45500
	Tully INTAKE				1000	116000	2000	119000
	Millers R. INTAKE				1200	124000	3000	128200
	TUNNELS & Outlet STRUCTURE				800	3000	1000	4800
	TOTALS				5000	270000	30000	305000

NOTE: THE ENERGY, LABOR, MATERIALS AND CHEMICAL COSTS ASSOCIATED WITH LABORATORY TESTING OF THE WATER SAMPLES HAVE BEEN INCLUDED UNDER THE ITEM - "WATER QUALITY MONITORING STATION AT MILLERS R."

3912 2/81

APPENDIX 6-3

UNIT COST CALCULATIONS

FILE:MILLERS.VC MILLERS AND MILLERS/TULLY ALTERNATIVES ECONOMIC DATA

MILLERS RIVER ALT.

ANNUAL Year		OPERATION Labor	and Energy	MAINTENANCE Materials	COSTS, Replace	in 1982 Other	dollars Total'82 $	Inflated current $	Present Value $	CAPITAL 1982 $	COSTS Inflated current $	Present Value $	CAPITAL and O&M Present Value $	WATER YIELD Maximum
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	2	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	3	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	4	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	5	0	0	0	0	0	0	0	0	16660000	21773953.707	14818987.0258	14818987.0258	0
1988	6	0	0	0	0	0	0	0	0	33320000	45943042.321	28951909.837	28951909.837	0
1989	7	0	0	0	0	0	0	0	0	33320000	48469909.649	28281726.739	28281726.739	0
1990	8	150000	5000	25000	75000	0	255000	391345.06132	211431.55974	0	0	0	211431.55974	12045
1991	9	150000	5000	25000	75000	0	255000	412869.0397	206537.31067	0	0	0	206537.31067	12045
1992	10	150000	5000	25000	75000	0	255000	435576.83688	201756.3544	0	0	0	201756.3544	12045
1993	11	150000	5000	25000	75000	0	255000	459533.56291	197086.06842	0	0	0	197086.06842	12045
1994	12	150000	5000	25000	75000	0	255000	484807.90887	192523.89091	0	0	0	192523.89091	12045
1995	13	150000	5000	25000	75000	0	255000	511472.34386	188067.31936	0	0	0	188067.31936	12045
1996	14	150000	5000	25000	75000	0	255000	539603.32277	183713.90919	0	0	0	183713.90919	12045
1997	15	150000	5000	25000	75000	0	255000	569281.50552	179461.27241	0	0	0	179461.27241	12045
1998	16	150000	5000	25000	75000	0	255000	600591.98832	175307.07629	0	0	0	175307.07629	12045
1999	17	150000	5000	25000	75000	0	255000	633624.54768	171249.04211	0	0	0	171249.04211	12045
2000	18	150000	5000	25000	75000	0	255000	668473.8978	167284.94392	0	0	0	167284.94392	12045
2001	19	150000	5000	25000	75000	0	255000	705239.96218	163412.60725	0	0	0	163412.60725	12045
2002	20	150000	5000	25000	75000	0	255000	744028.1601	159629.90801	0	0	0	159629.90801	12045
2003	21	150000	5000	25000	75000	0	255000	784949.70891	155934.77125	0	0	0	155934.77125	12045
2004	22	150000	5000	25000	75000	0	255000	828121.9429	152325.17006	0	0	0	152325.17006	12045
2005	23	150000	5000	25000	75000	0	255000	873668.64976	148799.12446	0	0	0	148799.12446	12045
2006	24	150000	5000	25000	75000	0	255000	921720.4255	145354.70028	0	0	0	145354.70028	12045
2007	25	150000	5000	25000	75000	0	255000	972415.0489	141990.00815	0	0	0	141990.00815	12045
2008	26	150000	5000	25000	75000	0	255000	1025897.87659	138703.2024	0	0	0	138703.2024	12045
2009	27	150000	5000	25000	75000	0	255000	1082322.2598	135492.48012	0	0	0	135492.48012	12045
2010	28	150000	5000	25000	75000	0	255000	1141849.9841	132356.08012	0	0	0	132356.08012	12045
2011	29	150000	5000	25000	75000	0	255000	1204651.7332	129292.28197	0	0	0	129292.28197	12045
2012	30	150000	5000	25000	75000	0	255000	1270907.5785	126299.405073	0	0	0	126299.405073	12045
2013	31	150000	5000	25000	75000	0	255000	1340807.4954	123375.807733	0	0	0	123375.807733	12045
2014	32	150000	5000	25000	75000	0	255000	1414551.9076	120519.866258	0	0	0	120519.866258	12045
2015	33	150000	5000	25000	75000	0	255000	1492352.2625	117730.074076	0	0	0	117730.074076	12045
2016	34	150000	5000	25000	75000	0	255000	1574431.637	115004.84088	0	0	0	115004.84088	12045
2017	35	150000	5000	25000	75000	0	255000	1661025.377	112342.691785	0	0	0	112342.691785	12045
2018	36	150000	5000	25000	75000	0	255000	1752381.7727	109742.166512	0	0	0	109742.166512	12045
2019	37	150000	5000	25000	75000	0	255000	1848762.7702	107201.838584	0	0	0	107201.838584	12045
2020	38	150000	5000	25000	75000	0	255000	1950444.7226	104720.314543	0	0	0	104720.314543	12045
TOTAL	xxxxxxxxxx	4650000	155000	775000	2325000	0	7905000	xxxxxxxxxxx	4714646.1069	83320000	xxxxxxxxxxx	72052623.603	76767269.71	373395

RESIDUAL VALUE xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxEnter res.val: 74970000 57343074 8.44 30787772.476 30787772.476 xxxxxxxxxxxxx

Inflate res val PV res value PV res value

NET PRESENT VALUE xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx 45979497.234 45979497.234

Total pv-res pv

NPV/MG xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx 123.139027663

NPV/Max MG

unit cost

constants	
investment per	30
planning period	38
inflation rate	0.055
discount rate	0.08

Enter capital cost: 87000000

111823615.387

Annual amortize capital cost 9933004.7469

0 0

FINANCIAL DATA

Actual	CAPITAL COST Amortized current $	CAPITAL and O&M Current $	COSTS Present Value $
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	4966502.3734	4966502.3734	3380118.0634
0	9933004.7469	9933004.7469	6259477.8952
0	9933004.7469	9933004.7469	5795812.8659
12045	9933004.7469	10324349.8082	5577924.9541
12045	9933004.7469	10345873.7866	5175512.6758
12045	9933004.7469	10368581.5838	4802659.4703
12045	9933004.7469	10392538.3098	4457181.5461
12045	9933004.7469	10417812.6558	4137056.7406
12045	9933004.7469	10444477.0907	3840412.5506
12045	9933004.7469	10472608.0697	3565515.0492
12045	9933004.7469	10502286.2524	3310758.6242
12045	9933004.7469	10533596.7352	3074656.4761
12045	9933004.7469	10566629.2946	2855831.8198
12045	9933004.7469	10601478.6447	2653009.738
12045	9933004.7469	10638244.7891	2465009.6388
12045	9933004.7469	10677032.907	2290738.2706
12045	9933004.7469	10717954.4558	2129183.2551
12045	9933004.7469	10761126.6898	1979407.0996
12045	9933004.7469	10806673.3966	1840541.6518
12045	9933004.7469	10854725.1724	1711782.9663
12045	9933004.7469	10905419.7958	1592386.5508
12045	9933004.7469	10958902.6235	1481662.9641
12045	9933004.7469	11015327.0067	1378973.741
12045	9933004.7469	11074854.731	1283727.6179
12045	9933004.7469	11137656.4801	1195377.0392
12045	9933004.7469	11203912.3254	1113414.921
12045	9933004.7469	11273812.2422	1037371.65594
12045	9933004.7469	11347556.6545	966812.3382
12045	9933004.7469	11425357.0094	901334.19625
12045	9933004.7469	11507436.3839	840564.21326
12045	4966502.3734	6627527.7504	440249.80863
12045	0	1752381.7727	109742.166512
12045	0	1848762.7702	107201.838584
12045	0	1950444.7226	104720.314543
373395	297990142.41	xxxxxxxxxx	83864130.717

Enter res.val: 74970000 573430748.44 30787772.476
PV-res value

xxxxxxxxxxxxx 53076358.242 - Total pv-res pv

123.139027663 xxxxxxxxxxxxxxxxxxxxxxxxxxxxx 142.14533736 - NPV/Actual MG
NPV/Actual MG unit cost

FILE:MILTULLY.VC MILLERS AND MILLERS/TULLY RIVER ALTERNATIVES ECONOMIC DATA
MILLERS/TULLY ALT.

ANNUAL		OPERATION	and	MAINTENANCE	COSTS,	in 1982	dollars			CAPITAL	COSTS		CAPITAL and O&M	WATER YIELD
Year		Labor	Energy	Materials	Replace	Other	Total'82 $	Inflated current $	Present Value $	1982 $	Inflated current $	Present Value $	Present Value $	Maximum
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	2	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	3	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	4	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	5	0	0	0	0	0	0	0	0	22510000	29419669.744	20022532.89	20022532.89	0
1988	6	0	0	0	0	0	0	0	0	45010000	62061714.732	39109407.617	39109407.617	0
1989	7	0	0	0	0	0	0	0	0	45010000	65475109.043	38204097.255	38204097.255	0
1990	8	270000	5000	30000	120000	0	425000	652241.76887	352385.93289	0	0	0	352385.93289	13870
1991	9	270000	5000	30000	120000	0	425000	688115.06616	344228.85111	0	0	0	344228.85111	13870
1992	10	270000	5000	30000	120000	0	425000	725961.3946	336260.59067	0	0	0	336260.59067	13870
1993	11	270000	5000	30000	120000	0	425000	765889.27151	328476.7807	0	0	0	328476.7807	13870
1994	12	270000	5000	30000	120000	0	425000	808013.18145	320873.15152	0	0	0	320873.15152	13870
1995	13	270000	5000	30000	120000	0	425000	852453.90643	313445.53227	0	0	0	313445.53227	13870
1996	14	270000	5000	30000	120000	0	425000	899338.87128	306199.84865	0	0	0	306189.84865	13870
1997	15	270000	5000	30000	120000	0	425000	948802.5092	299102.12068	0	0	0	299102.12068	13870
1998	16	270000	5000	30000	120000	0	425000	1000985.64721	292178.46048	0	0	0	292178.46048	13870
1999	17	270000	5000	30000	120000	0	425000	1056040.9128	285415.07019	0	0	0	285415.07019	13870
2000	18	270000	5000	30000	120000	0	425000	1114123.163	278808.23986	0	0	0	278808.23986	13870
2001	19	270000	5000	30000	120000	0	425000	1175399.937	272354.34542	0	0	0	272354.34542	13870
2002	20	270000	5000	30000	120000	0	425000	1240046.9335	266049.84668	0	0	0	266049.84668	13870
2003	21	270000	5000	30000	120000	0	425000	1308249.5148	259891.28542	0	0	0	259891.28542	13870
2004	22	270000	5000	30000	120000	0	425000	1380203.2392	253875.28344	0	0	0	253875.28344	13870
2005	23	270000	5000	30000	120000	0	425000	1456114.4163	247998.54077	0	0	0	247998.54077	13870
2006	24	270000	5000	30000	120000	0	425000	1536200.7092	242257.8338	0	0	0	242257.8338	13870
2007	25	270000	5000	30000	120000	0	425000	1620691.7482	236650.01358	0	0	0	236650.01358	13870
2008	26	270000	5000	30000	120000	0	425000	1709829.7943	231172.004	0	0	0	231172.004	13870
2009	27	270000	5000	30000	120000	0	425000	1803870.433	225820.80021	0	0	0	225820.80021	13870
2010	28	270000	5000	30000	120000	0	425000	1903083.3068	220593.46687	0	0	0	220593.46687	13870
2011	29	270000	5000	30000	120000	0	425000	2007752.8887	215487.13662	0	0	0	215487.13662	13870
2012	30	270000	5000	30000	120000	0	425000	2118179.2976	210499.00845	0	0	0	210499.00845	13870
2013	31	270000	5000	30000	120000	0	425000	2234679.1589	205626.34622	0	0	0	205626.34622	13870
2014	32	270000	5000	30000	120000	0	425000	2357586.5127	200866.4771	0	0	0	200866.4771	13870
2015	33	270000	5000	30000	120000	0	425000	2487253.7709	196216.79013	0	0	0	196216.79013	13870
2016	34	270000	5000	30000	120000	0	425000	2624052.7283	191674.7348	0	0	0	191674.7348	13870
2017	35	270000	5000	30000	120000	0	425000	2768375.6283	187237.81964	0	0	0	187237.81964	13870
2018	36	270000	5000	30000	120000	0	425000	2920636.2879	182903.61085	0	0	0	182903.61085	13870
2019	37	270000	5000	30000	120000	0	425000	3081271.2837	178669.73097	0	0	0	178669.73097	13870
2020	38	270000	5000	30000	120000	0	425000	3250741.3043	174533.85757	0	0	0	174533.85757	13870
TOTAL	xxxxxxxxxx	8370000	155000	930000	3720000	0	13175000	xxxxxxxxxx	7857743.5116	112530000	xxxxxxxxxx	97336037.762	105193781.274	429970
RESIDUAL VALUE	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	Enter res.val:	101280000	774670751 Inflate res val	41592444.929 PV res value	41592444.929 PV res value	xxxxxxxxxx
NET PRESENT VALUE	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	63601336.345 Total pv-res pv	63601336.345
NPV/MG	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	xxxxxxxxxx	147.92040455 NPV/Max MG unit cost

constants	
investment per	30
planning period	38
inflation rate	0.055
discount rate	0.08

Enter capital cost: 112530000

151062562.3

Annual amortize capital cost 13418499.6899

FINANCIAL DATA

Actual	CAPITAL COST Amortized $	CAPITAL and O&M Current $	COSTS Present Value $
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	6709249.8449	6709249.8449	4566202.7092
0	13418499.6899	13418499.6899	8455930.9429
0	13418499.6899	13418499.6899	7829565.6879
13870	13418499.6899	14070741.4588	7601983.792
13870	13418499.6899	14106614.756	7056819.4614
13870	13418499.6899	14144461.0847	6551622.2669
13870	13418499.6899	14184308.9614	6083441.2957
13870	13418499.6899	14226512.8713	5649543.9988
13870	13418499.6899	14270953.5963	5247400.0205
13870	13418499.6899	14317838.5612	4874666.2266
13870	13418499.6899	14367302.1991	4529172.841
13870	13418499.6899	14419486.3371	4208910.6089
13870	13418499.6899	14474540.6027	3912018.9113
13870	13418499.6899	14532622.8529	3636774.7594
13870	13418499.6899	14593899.6269	3381582.6043
13870	13418499.6899	14658546.6234	3144964.9012
13870	13418499.6899	14726749.2047	2925553.3729
13870	13418499.6899	14798702.9281	2722080.92
13870	13418499.6899	14874614.1062	2533374.1302
13870	13418499.6899	14954700.399	2358346.3425
13870	13418499.6899	15039191.438	2195991.2254
13870	13418499.6899	15128329.4842	2045376.8297
13870	13418499.6899	15222370.1229	1905640.0833
13870	13418499.6899	15321582.9967	1775981.6919
13870	13418499.6899	15426252.5786	1655661.4191
13870	13418499.6899	15536678.9875	1543993.7145
13870	13418499.6899	15653178.8488	1440343.6666
13870	13418499.6899	15776086.2026	1344123.2552
13870	13418499.6899	15905753.4698	1254787.881
13870	13418499.6899	16042552.4182	1171833.1523
13870	6709249.8449	9477625.4733	641014.86476
13870	0	2920636.2879	182903.61085
13870	0	3081271.2837	178669.73097
13870	0	3250741.2043	174533.85757
429970	402554990.7	xxxxxxxxxxx	114780810.777

Enter res.val: 10128000 774670751 41592444.929
PV-res value

xxxxxxxxxxxxxx 73188365.848 - Total pv-res pv

147.92040455 xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx 170.2173776 - NPV/Actual MG
NPV/Actual MG

APPENDIX 6-4

HYDRODYNAMIC DIVERSION SIMULATIONS FOR QUABBIN RESERVOIR

J. E. EDINGER ASSOCIATES, INC.
Consultants in Environmental Hydrology and Waterbody Dynamics

John Eric Edinger
Edward M. Buchak

37 West Avenue
Wayne, Pennsylvania 19087
215 293 0757

16 September 1983

Mr. Ron Sharpin
Wallace, Floyd Associates, Inc.
Russia Wharf
286 Congress Street
Boston, MA 02210

Dear Ron:

Re: Diversion Simulations for Millers Alternative

Attached are summaries of the diversion simulations for Case 1, the Millers diversion outfall at the northern tip of the main body, and Case 2, the outfall at the northern tip of the western arm of Quabbin Reservoir. Inflow and outflow rates, as well as the initial elevation, are based on Dave Hellstrom's Millers simulation for 1967 (memorandum of 11 July 1983). Inflow and initial temperatures and meteorological data are as constructed for the Verification and Drawdown Cases of last year.

Diversion Analysis

The Millers diversion for the year 1967 begins in March and continues through June. Our simulations begin on 1 February in order that the velocity and temperature fields are properly initialized with time-varying meteorological and inflow data. The simulations continue to 15 October, just before fall overturn. In order to provide confidence in the simulations, we have compared the simulation results to two previous results. The first comparison is our computed elevations to those computed and presented by Dave Hellstrom.

These are show in Figure 1. A slight deviation between these two computed numbers begins to appear in June. This deviation is because of differences in evaporation rates. Dave used the long term, mean monthly pan evaporation rate attributed to Fitzgerald and applied to lakes by reducing the rate by 0.7. Our evaporation computation is based on combined heat and water budgets and is done every time step using hourly, observed dew point temperature and wind speed for 1967 at Westover Air Force Base and the computed surface temperature profile.

The second comparison is with the verification case temperature profiles at the peak of the diversion inflow around day 144. The two inflow points, Segment 32 and Segment 4, and the location of the Shaft 12 withdrawal, Segment 18, represent extreme locations for comparing differences in the profiles. Segment 32, shown in Table 1 for the Verification Case, Case 1 and Case 2 is the location of the Millers diversion for Case 1. The direct effect of the diversion is shown in the middle profile. Comparison to the Verification Case (first profile) shows that the epilimnetic temperatures are higher and the hypolimnetic temperatures are lower. Thus, with the Millers diversion into Segment 32, there is stronger stratification at that point.

Case 2 has a similar effect at Segment 32 of increasing surface temperature and decreasing bottom temperatures. However, this effect on Segment 32 is less than the Case 1 diversion.

Temperature profiles for Segment 4 are given in Table 2 for the three cases. Comparison of the Case 2 profile to the Verification Case profile shows higher surface temperatures and lower bottom temperatures. Stratification is increased by the diversion flow. There is also some increase in stratification due to the Case 1 diversion.

At Shaft 12, shown in Table 3, there is little effect of either diversion on the surface temperatures; there is a decrease in bottom temperatures.

Diversion Dye Test

Millers water was given a numerical dye concentration of 100 mg/L in the simulations. This concentration was maintained regardless of flow, and thus the dye dump (mass) rate varied with the flow. This procedure allows the concentrations to be interpreted as percentages of Millers River water at any particular time and location. Figure 2 shows the dye concentration history for the intake at Shaft 12 for both the main body and western arm releases as well as the dye dump rate. The Shaft 12 intake is vertically extensive and the concentrations presented in Figure 2 are the average at the four layers in front of the intake. For Case 1 the figures show that Millers River water appears at Shaft 12 in small concentrations on day 101, 41 days after the initial entry of Millers water. Millers River water arrives in substantial quantities on day 122 with steady values of about 10 percent by day 173. The sharp rise in dye concentration that occurs on day 139 is due to a wind event that mixes Millers River water longitudinally in the main body.

For Case 2 (the diversion outfall in the western arm), dye first appears on day 133 with steady values obtaining by day 154. The steady values for both Case 1 and Case 2 are very close -- each about 10 percent. This proportion is close to, but less than the 15.1 percent computed as the ratio of transferred volume to current storage in my letter of 3 August 1983.

Figure 3 shows the concentration history for the Chicopee intake at Windsor Dam. For Case 1 (outfall in the main body), dye concentrations first appear on day 143. For Case 2, the outfall at the head of the western arm,

dye appears at the Chicopee intake on day 120 and rises to steady values of 13 percent by day 177. Dates and concentrations for both cases and locations are summarized in Table 4.

The accompanying listings are the output from these two simulations. The simulation can be identified by the phrase "Diversion Outfall at Main Body" or "Diversion Outfall at Western Arm". Page 3 shows a schematic map of the longitudinal-vertical grid for Quabbin. Segment numbers are across the top and may be referenced to the map, Figure 4. Layer numbers are down the side; these layers are at two meter intervals. Page 9 gives the elevation in meters at the top of each one of these layers. Pages 6 through 9 give the elevation-area-volume tables for each branch as well as the reservoir as a whole. Following them is the presentation of initial conditions for day 32. Then begin the snapshots of instantaneous, longitudinal-vertical detail throughout the simulation period at seven-day intervals. The tables of greatest concern are labeled T2, which is temperature, and C2, which is the dye concentration in mg/L. The latter may also be read as percent of Millers River water. The segments in each of the tables are presented from left to right in the following order: south to north in the eastern arm; north to south in the main body; and, north to south in the western arm. For Case 1, diversion outfall at the main body, the Millers River enters segment 32. For Case 2, diversion in the western arm, the Millers River enters segment 2, which is not shown. Segment 4 is nearest and is 4.6 km downstream. The Shaft 12 intake is located in segment 18, layers 10 to 13. Chicopee intake at Winsor Dam is at segment 9, layer 11.

The last four pages of each listing show the concentration histories at a number of points throughout the reservoir. These are presented as daily values and it is from these tables that the Figure 2 and Figure 3 were

constructed. Note that the Millers diversion water occurs primarily in April and May with a small amount in March and a moderate amount in June.

Please contact me if you have any questions concerning this material. A telephone conference can be quite valuable in helping me present these simulation results.

Sincerely yours,

Edward M. Buchak

Edward M. Buchak

llb

Attachments

xc: P. Erickson
D. Hellstrom

Figure 1

Comparison of Computed Elevations - Hydrodynamic and Safe Yield Models

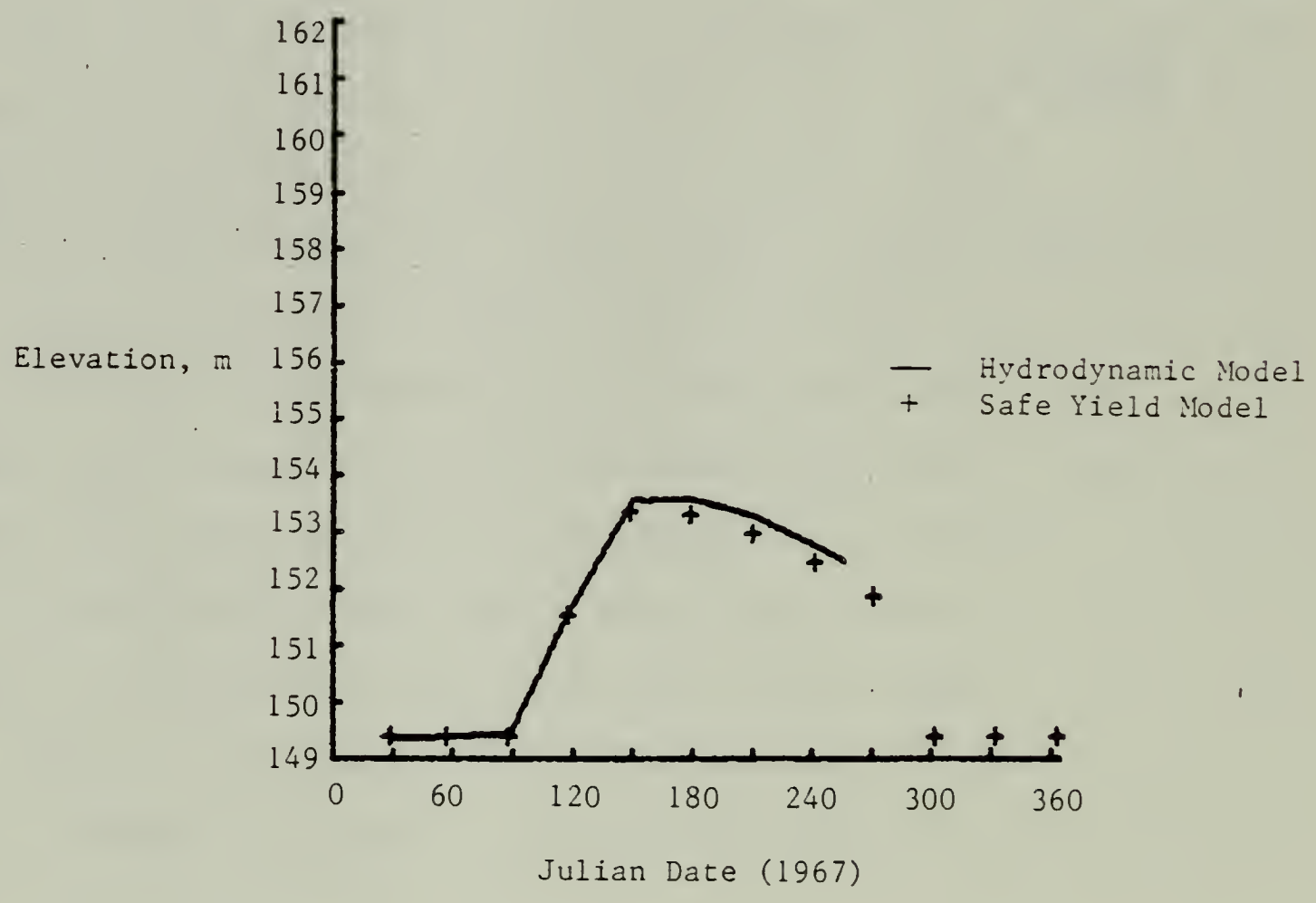


Figure 2

Dye Dump Rate and Computed Concentration Histories at Shaft 12 for the Diversion Outfall at the Main Body (Segment 32) and at the Western Arm (Segment 2)

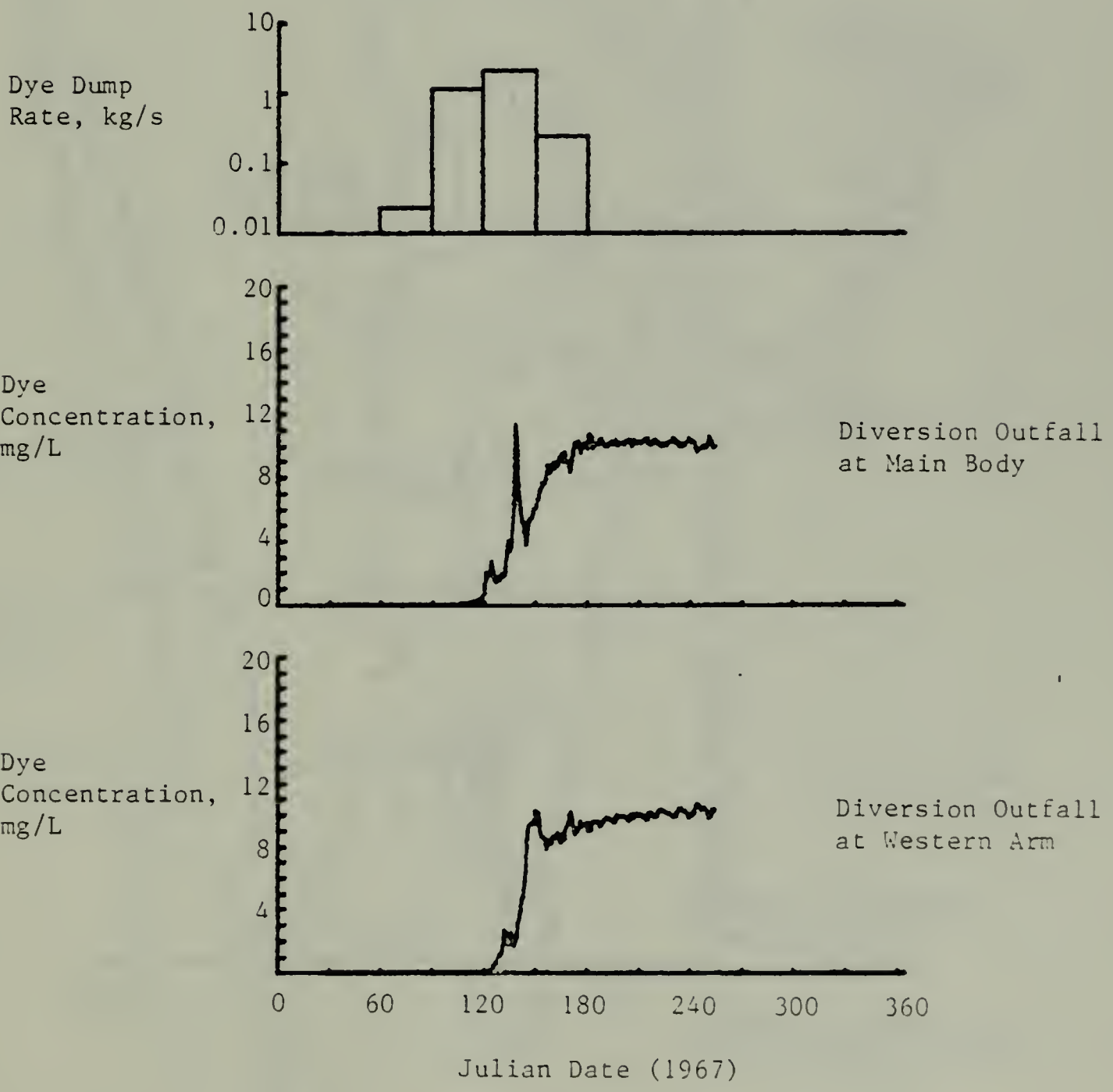


Figure 3

Dye Dump Rate and Computed Concentration Histories at Windsor Dam (Chicopee Aqueduct) for the Diversion Outfall at the Main Body (Segment 32) and at the Western Arm (Segment 2)

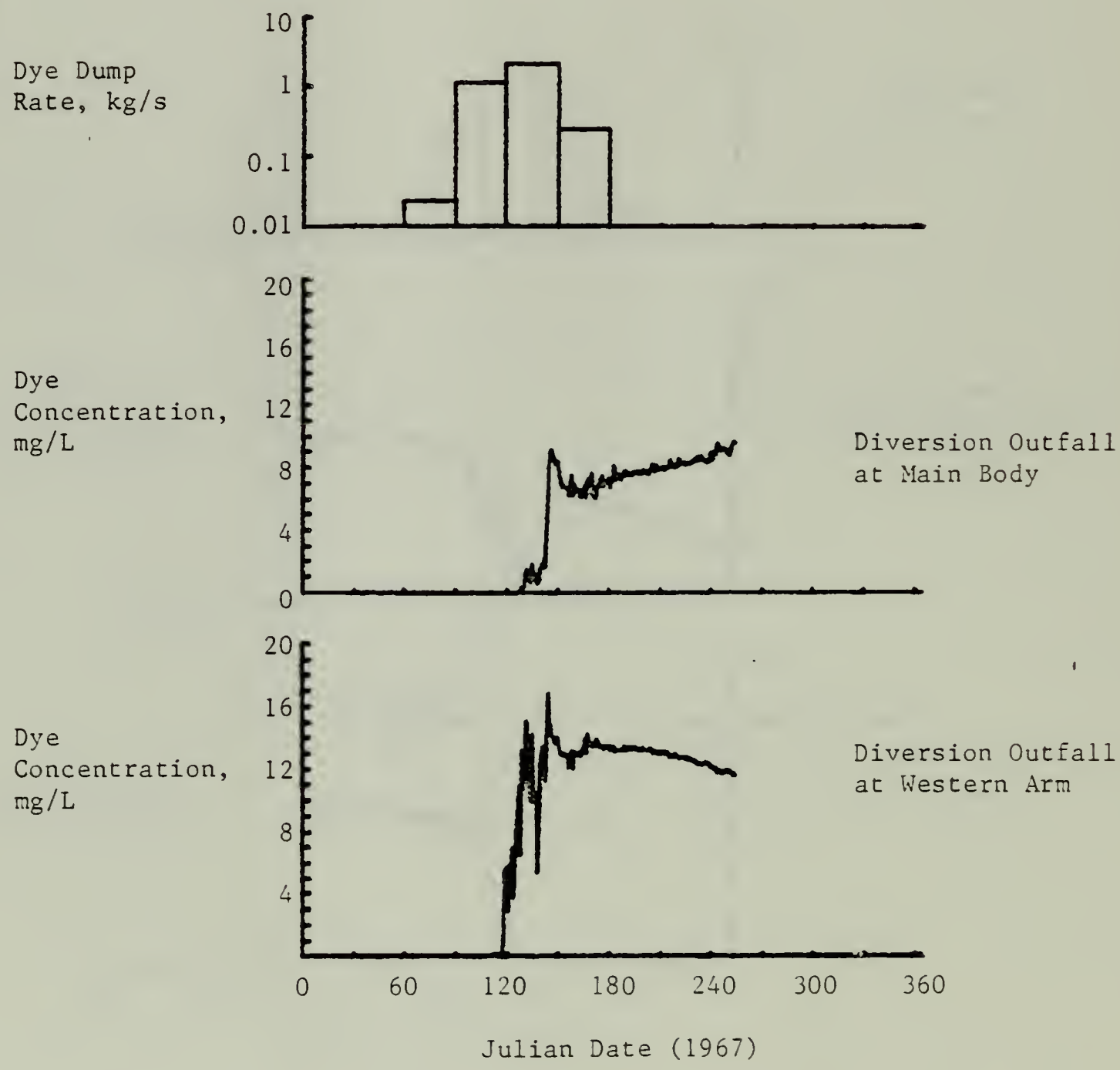


Figure 4

LARM Segments and
Temperature Observation Stations

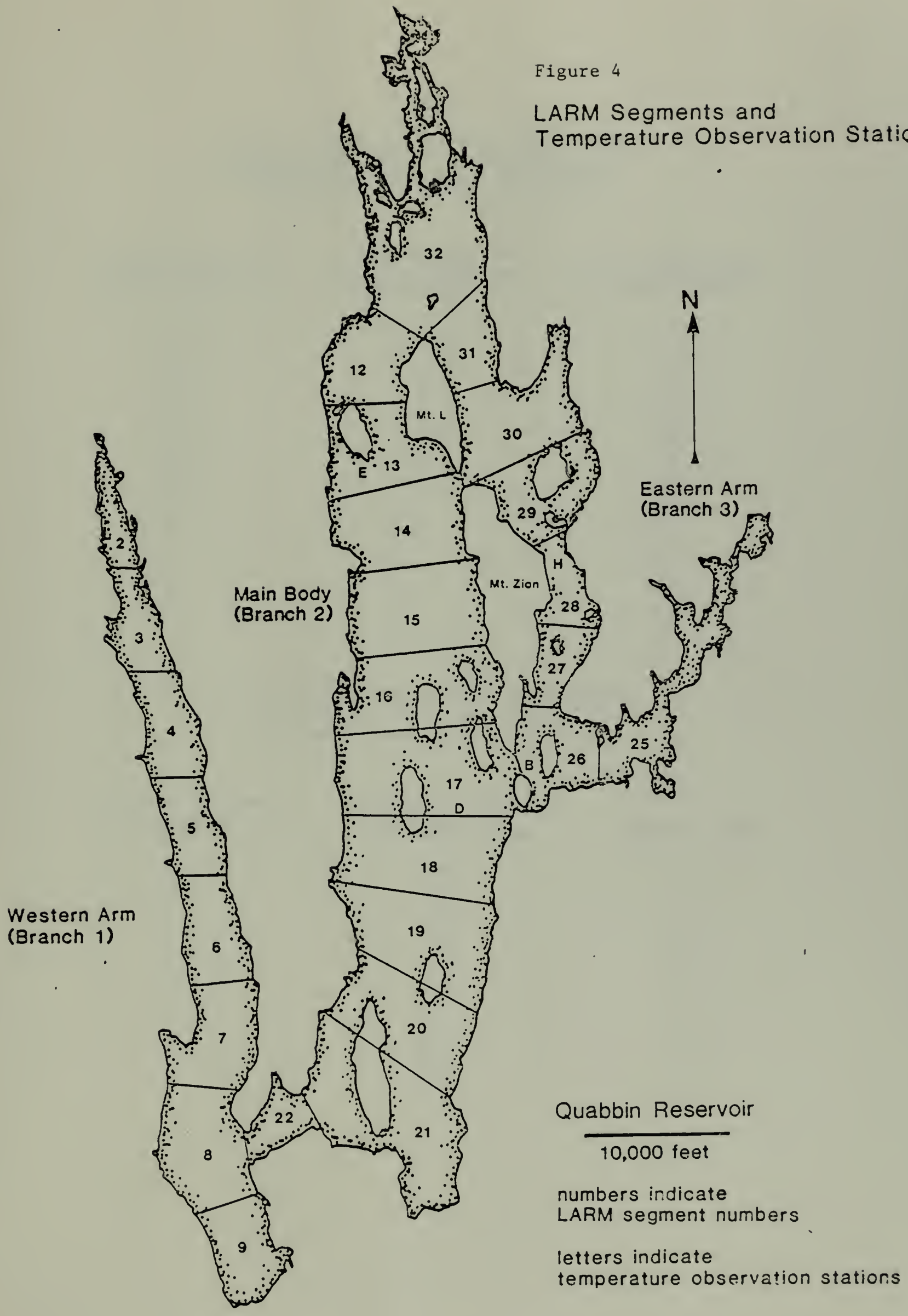


Table 1

Segment 32, Temperature Profiles for
Verification Case, Case 1 and Case 2
on Day 144 at 2 Meter Intervals

Verification	Case 1 - Outfall at Main Body	Case 2 - Outfall at Western Arm
10.9	12.9	12.1
10.9	12.9	12.1
10.9	11.5	10.9
10.5	9.8	9.5
9.5	8.7	8.3
8.4	7.3	7.0
7.4	6.2	6.0
6.7	5.5	5.3
6.2	4.9	4.7

Table 2

Segment 4, Temperature Profiles for
Verification Case, Case 1 and Case 2
on Day 144 at 2 Meter Intervals

Verification	Case 1 - Outfall at Main Body	Case 2 - Outfall at Western Arm
9.9	10.5	11.4
9.9	9.4	9.8
9.2	8.6	8.8
8.6	8.1	8.1
8.1	7.5	7.5
7.6	7.0	7.0
7.3	6.6	6.6
6.9	6.2	6.2
6.6	5.8	5.8
6.4	5.5	5.5
6.1	5.3	5.3

Table 3

Segment 18, Temperature Profiles for
Verification Case, Case 1 and Case 2
on Day 144 at 2 Meter Intervals

Verification	Case 1 - Outfall at Main Body	Case 2 - Outfall at Western Arm
10.2	10.8	10.7
10.2	9.8	9.8
9.4	8.9	9.0
8.6	8.3	8.4
7.9	7.7	7.9
7.5	7.2	7.3
7.1	6.7	6.8
6.8	6.1	6.3
6.5	5.7	5.8
6.3	5.3	5.4
6.1	5.1	5.2
5.9	4.9	5.0
5.8	4.7	4.8
5.7	4.7	4.7

Table 4

Summary of Dye Concentrations at Shaft 12 and Chicopee Aqueduct for Cases 1 and 2 for Diversion Beginning on Day 60

	Case 1 - Outfall at Main Body	Case 2 - Outfall at Western Arm
Shaft 12		
Arrival of Millers River Water	day 122	day 133
Date and Peak Concentration	11.4 mg/L on day 139	10.7 mg/L on day 245
Steady Value	10 mg/L	10 mg/L
Chicopee Aqueduct		
Arrival of Millers River Water	day 143	day 120
Date and Peak Concentration	9.7 mg/L on day 257	16.8 mg/L on day 145
Steady Value	9 mg/L	12 mg/L

JULIAN DATE CALENDAR

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1	001	032	060	091	121	152	182	213	244	274	305	335	1
2	002	033	061	092	122	153	183	214	245	275	306	336	2
3	003	034	062	093	123	154	184	215	246	276	307	337	3
4	004	035	063	094	124	155	185	216	247	277	308	338	4
5	005	036	064	095	125	156	186	217	248	278	309	339	5
6	006	037	065	096	126	157	187	218	249	279	310	340	6
7	007	038	066	097	127	158	188	219	250	280	311	341	7
8	008	039	067	098	128	159	189	220	251	281	312	342	8
9	009	040	068	099	129	160	190	221	252	282	313	343	9
10	010	041	069	100	130	161	191	222	253	283	314	344	10
11	011	042	070	101	131	162	192	223	254	284	315	345	11
12	012	043	071	102	132	163	193	224	255	285	316	346	12
13	013	044	072	103	133	164	194	225	256	286	317	347	13
14	014	045	073	104	134	165	195	226	257	287	318	348	14
15	015	046	074	105	135	166	196	227	258	288	319	349	15
16	016	047	075	106	136	167	197	228	259	289	320	350	16
17	017	048	076	107	137	168	198	229	260	290	321	351	17
18	018	049	077	108	138	169	199	230	261	291	322	352	18
19	019	050	078	109	139	170	200	231	262	292	323	353	19
20	020	051	079	110	140	171	201	232	263	293	324	354	20
21	021	052	080	111	141	172	202	233	264	294	325	355	21
22	022	053	081	112	142	173	203	234	265	295	326	356	22
23	023	054	082	113	143	174	204	235	266	296	327	357	23
24	024	055	083	114	144	175	205	236	267	297	328	358	24
25	025	056	084	115	145	176	206	237	268	298	329	359	25
26	026	057	085	116	146	177	207	238	269	299	330	360	26
27	027	058	086	117	147	178	208	239	270	300	331	361	27
28	028	059	087	118	148	179	209	240	271	301	332	362	28
29	029		088	119	149	180	210	241	272	302	333	363	29
30	030		089	120	150	181	211	242	273	303	334	364	30
31	031		090		151		212	243		304		365	31

APPENDIX 6-5

TECHNICAL APPENDIX ON WATER QUALITY AND ECOLOGY
FOR
TASK 6: MILLERS AND TULLY RIVERS ALTERNATIVE

Published Under Separate Cover

Prepared By:

New England Research, Inc.

APPENDIX 6-6

TECHNICAL APPENDIX ON WATER QUALITY
FOR
TASK 6: MILLERS AND TULLY RIVERS ALTERNATIVE

Published Under Separate Cover

Prepared By:

Normandeau Associates, Inc.

APPENDIX 6-7

TECHNICAL APPENDIX ON AQUATIC ECOLOGY
FOR
TASK 6: MILLERS AND TULLY RIVERS ALTERNATIVE

Published Under Separate Cover

Prepared By:

Normandeau Associates, Inc.

APPENDIX 6-8

TECHNICAL APPENDIX ON TERRESTRIAL ECOLOGY
FOR
TASK 6: MILLERS AND TULLY RIVERS ALTERNATIVE

Published Under Separate Cover

Prepared By:

Normandeau Associates, Inc.